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Peyton et al.

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(54) **APPARATUS FOR IDENTIFYING INTERCONNECTIONS AND DETERMINING THE PHYSICAL STATE OF CABLE LINES IN A NETWORK**

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(73) Assignee: **Cable Sense Limited**, Lancaster (GB)

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H04Q 1/02 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 43/50*** (2013.01); ***H04Q 1/136*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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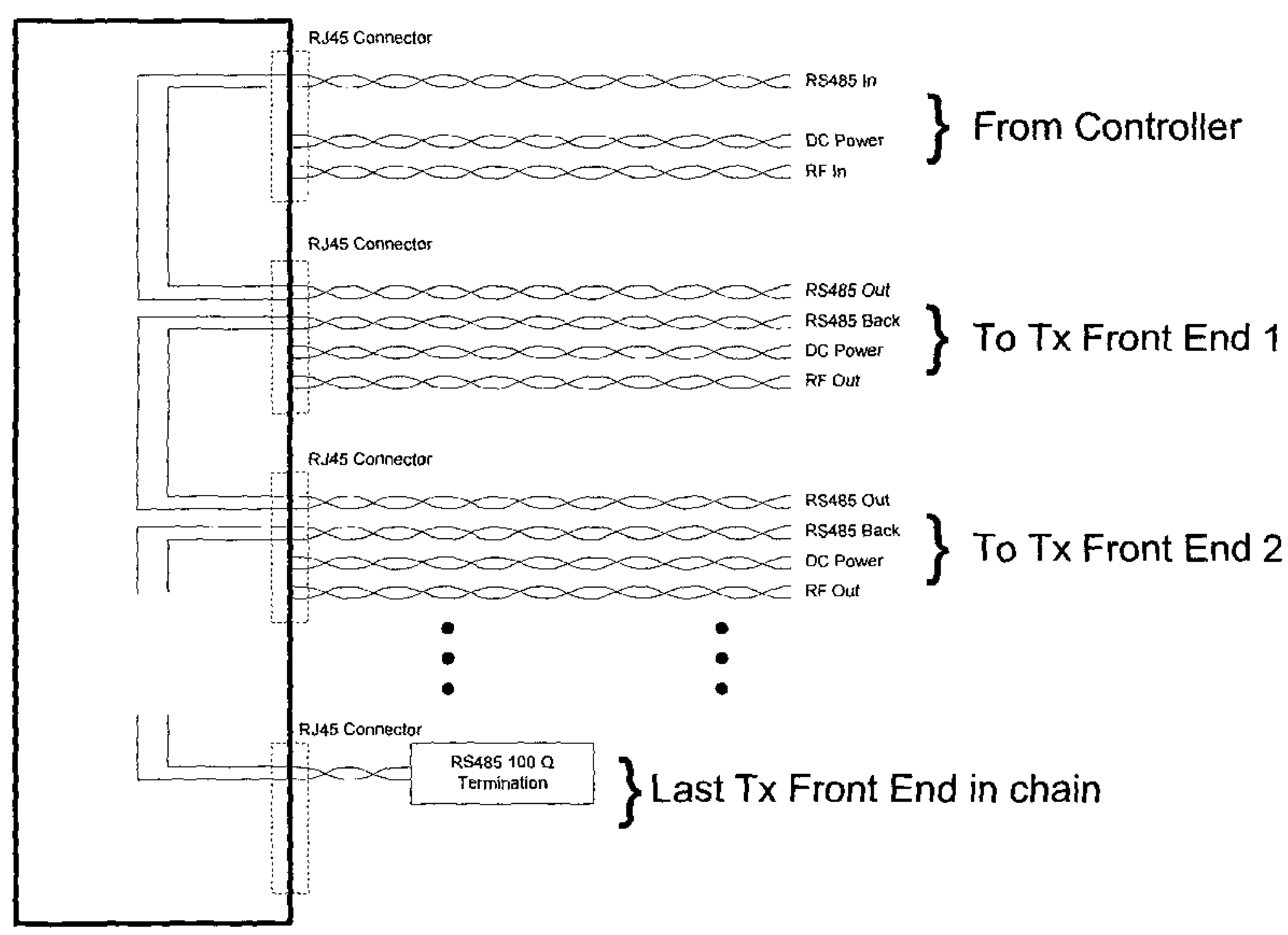
(57) **ABSTRACT**

An apparatus for identifying interconnections in a network. The apparatus comprises a plurality of transmitter coupling units, a plurality of receiver coupling units, and an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network. In some embodiments, the interconnection identification means is configured to, if any one of the transmitter coupling units is coupled to the same cable line as a selected one of the receiver coupling units, identify the interconnection between the transmitter coupling unit and the selected receiver coupling unit according to by a binary tree search algorithm.

23 Claims, 23 Drawing Sheets



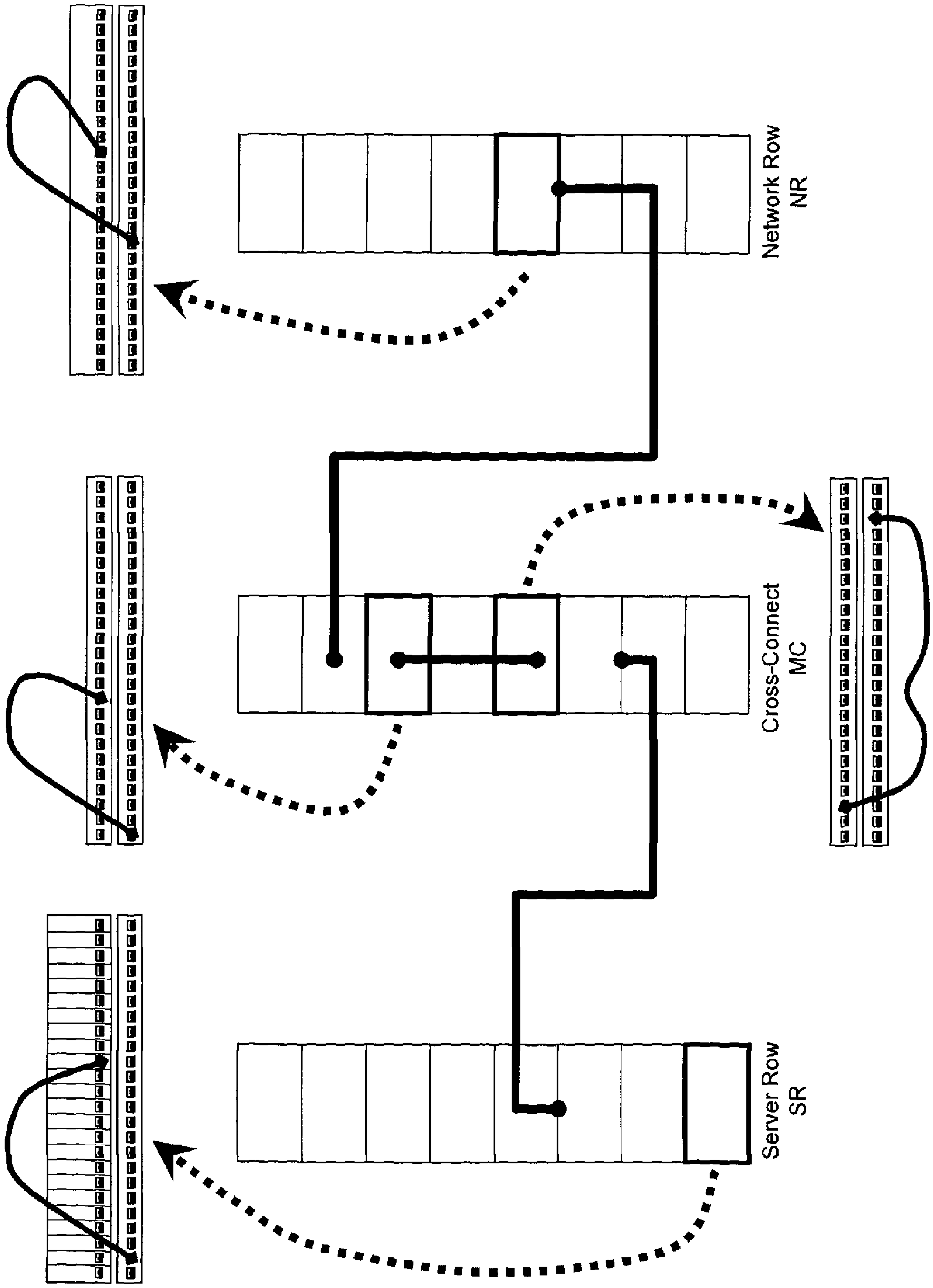


Figure 1

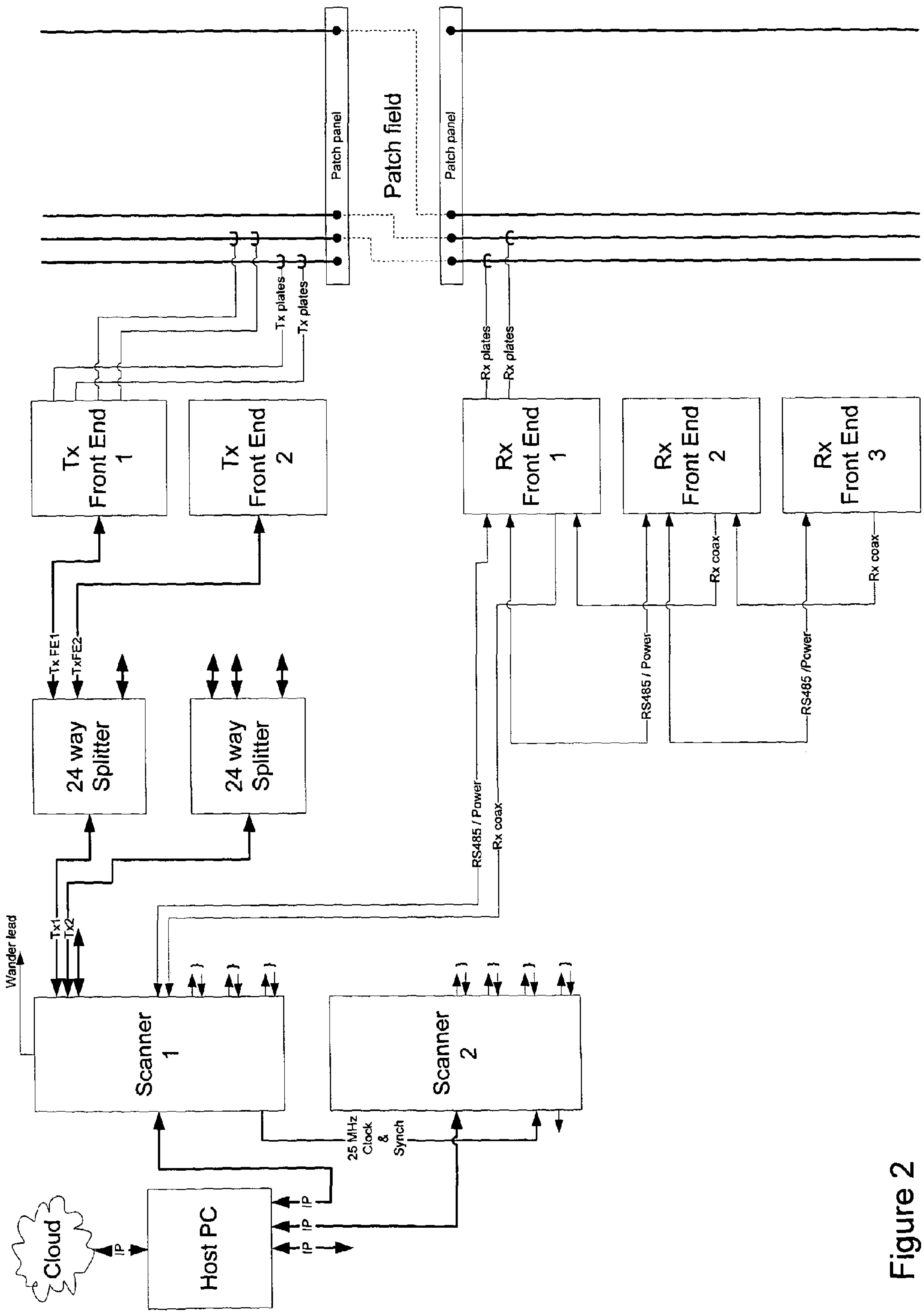

Patch panel
Patch field
Patch panel
Tx plates
Tx plates
Rx plates
Rx plates
Tx Front End 1
Tx Front End 2
Rx Front End 1
Rx Front End 2
Rx Front End 3
Rx coax
Rx coax
Tx FE1
TxFE2
RS485 / Power
RS485 /Power
24 way Splitter
24 way Splitter
RS485 / Power
Rx coax
Wander lead
Tx1
Tx2
Scanner 1
Scanner 2
25 MHz Clock & Synch
Cloud
IP
Host PC
IP
IP
IP

Figure 2

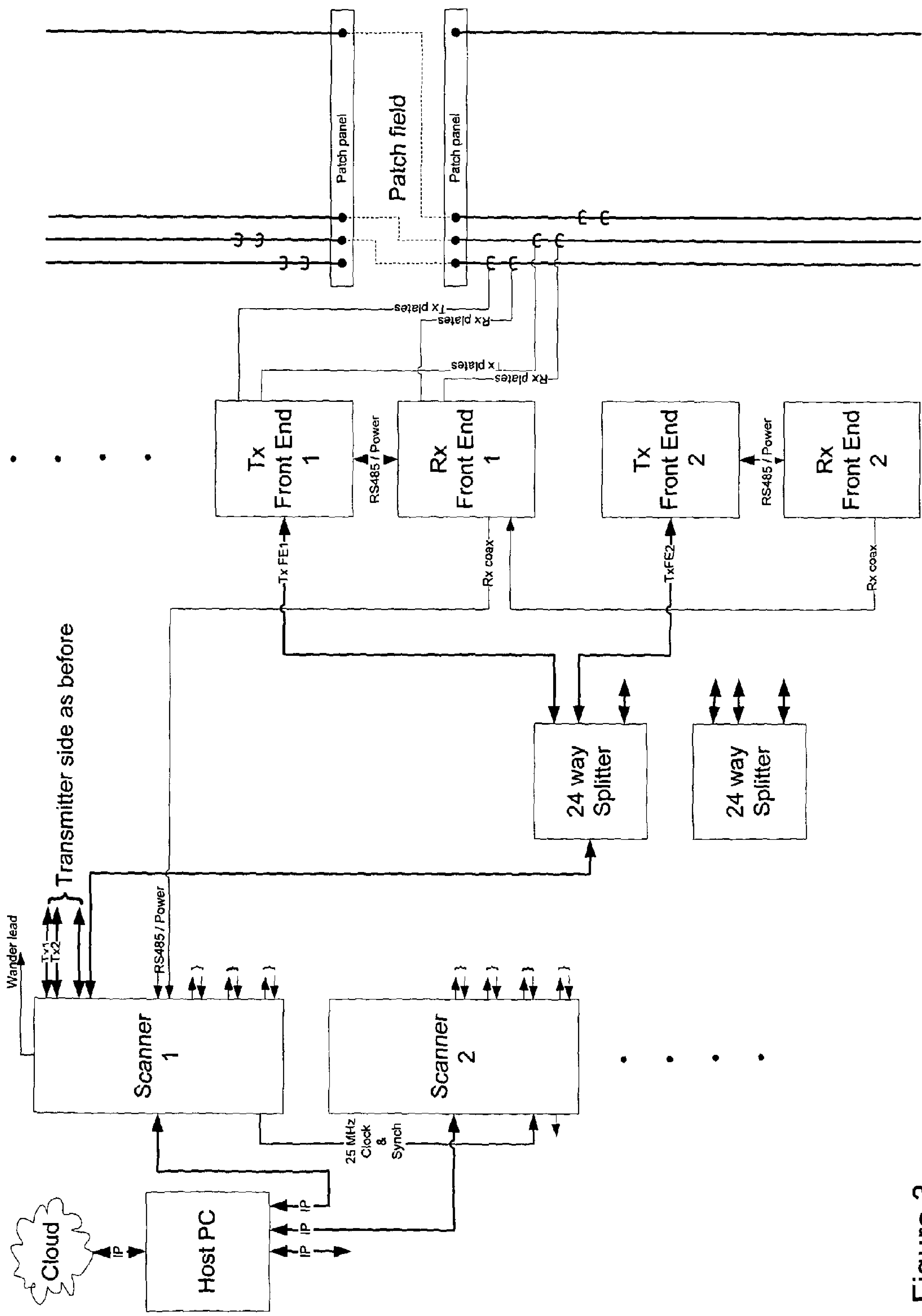

Patch panel
Patch field
Patch panel
Tx plates
Rx plates
Tx plates
Rx plates
Tx Front End 1
RS485 / Power
Rx Front End 1
Tx Front End 2
RS485 / Power
Rx Front End 2
Tx FE1
Rx coax
TxFE2
Rx coax
24 way Splitter
24 way Splitter
Transmitter side as before
Wander lead
Tx1
Tx2
RS485 / Power
Scanner 1
Scanner 2
25 MHz Clock & Synch
Cloud
IP
Host PC
IP
IP
IP
IP

Figure 3

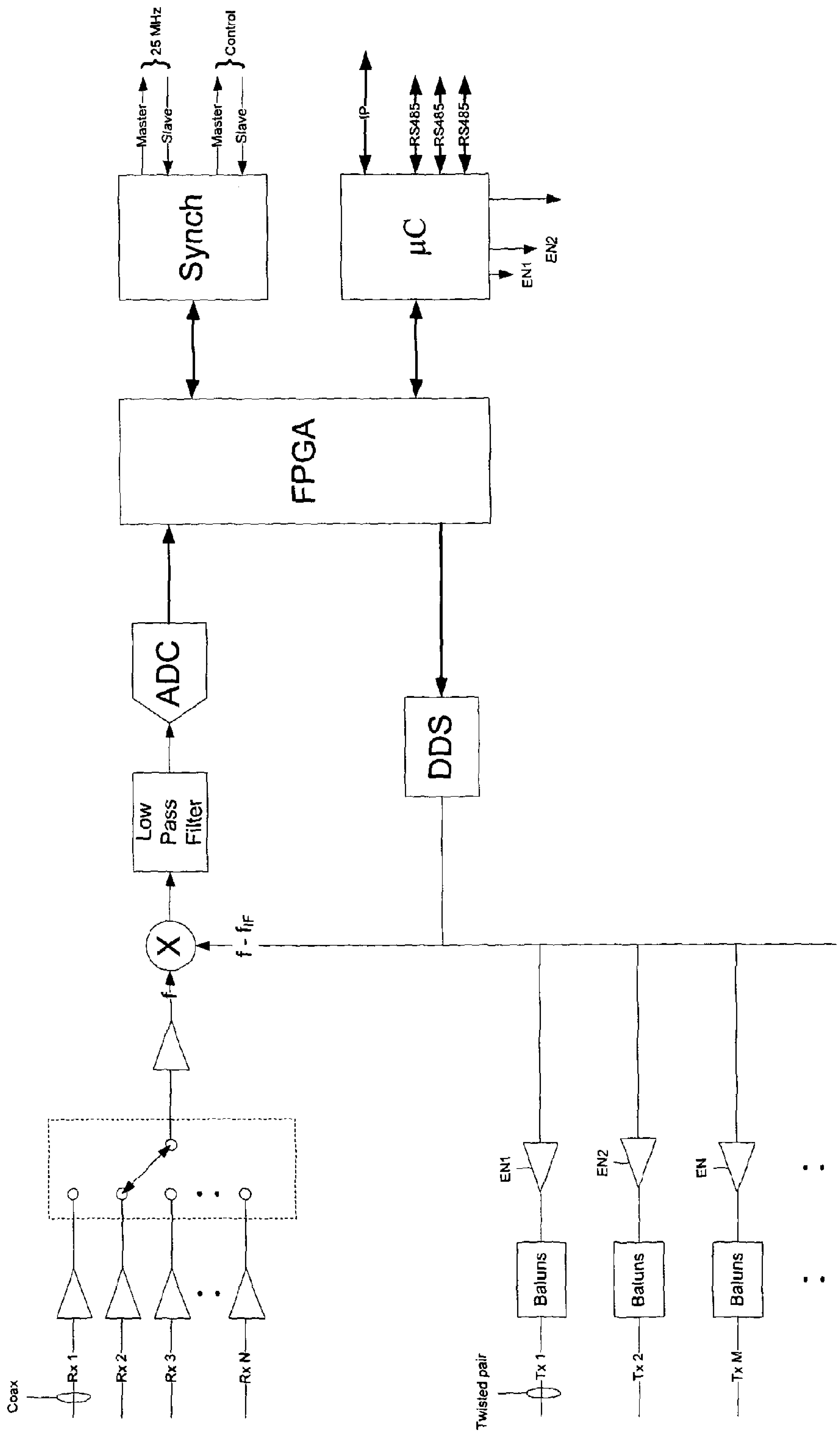

Master
Slave
25 MHz
Master
Slave
Control
IP
RS485
RS485
RS485
Synch
µC
EN1
EN2
FPGA
ADC
DDS
Low
Pass
Filter
f
f - f_IF
Coax
Rx 1
Rx 2
Rx 3
Rx N
Twisted pair
Tx 1
Tx 2
Tx M
Baluns
Baluns
Baluns
EN1
EN2
EN

Figure 4

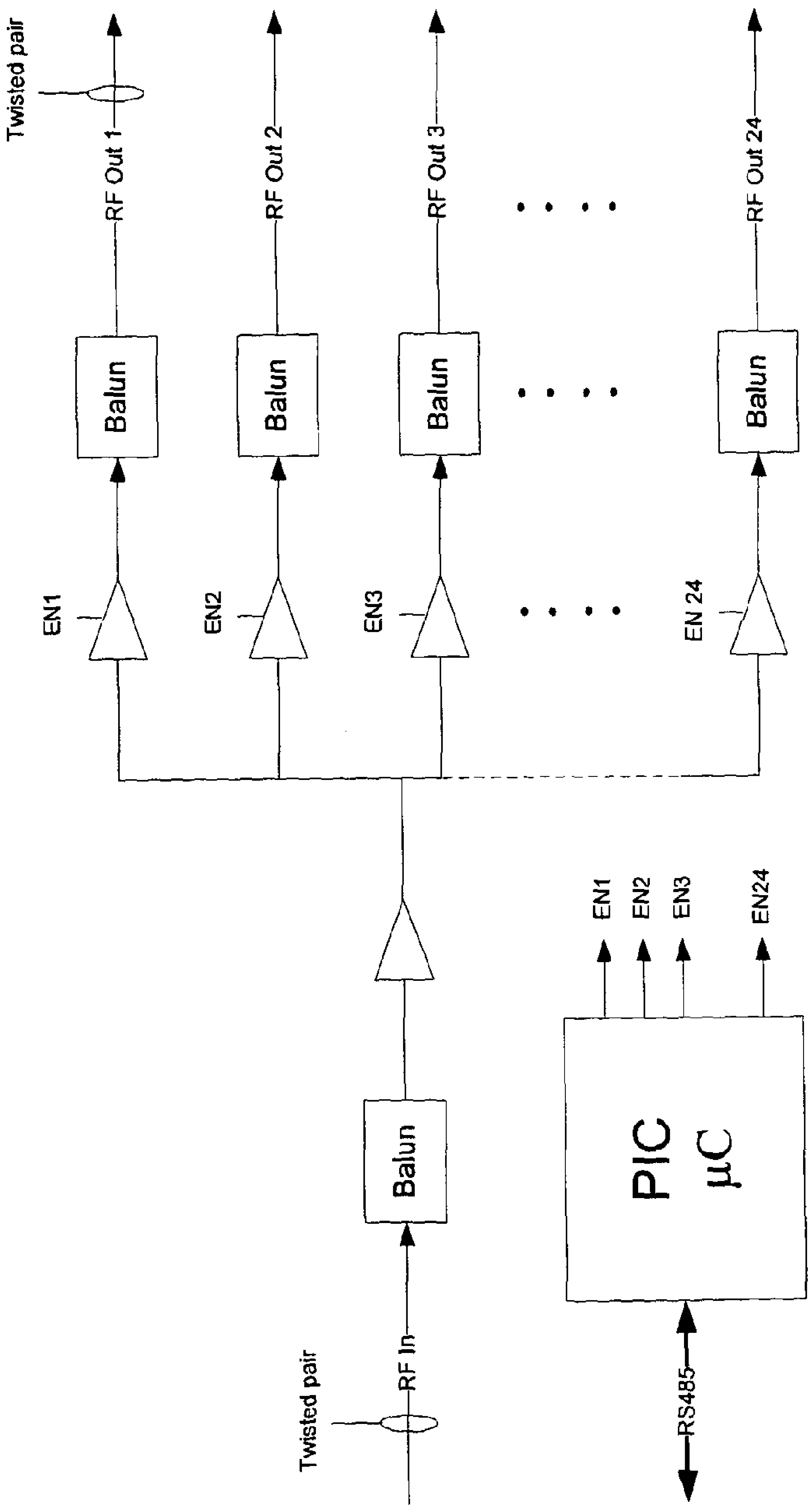

Twisted pair
RF Out 1
RF Out 2
RF Out 3
RF Out 24
Balun
Balun
Balun
Balun
EN1
EN2
EN3
EN 24
EN1
EN2
EN3
EN24
PIC
μC
Balun
Twisted pair
RF In
RS485

Figure 5

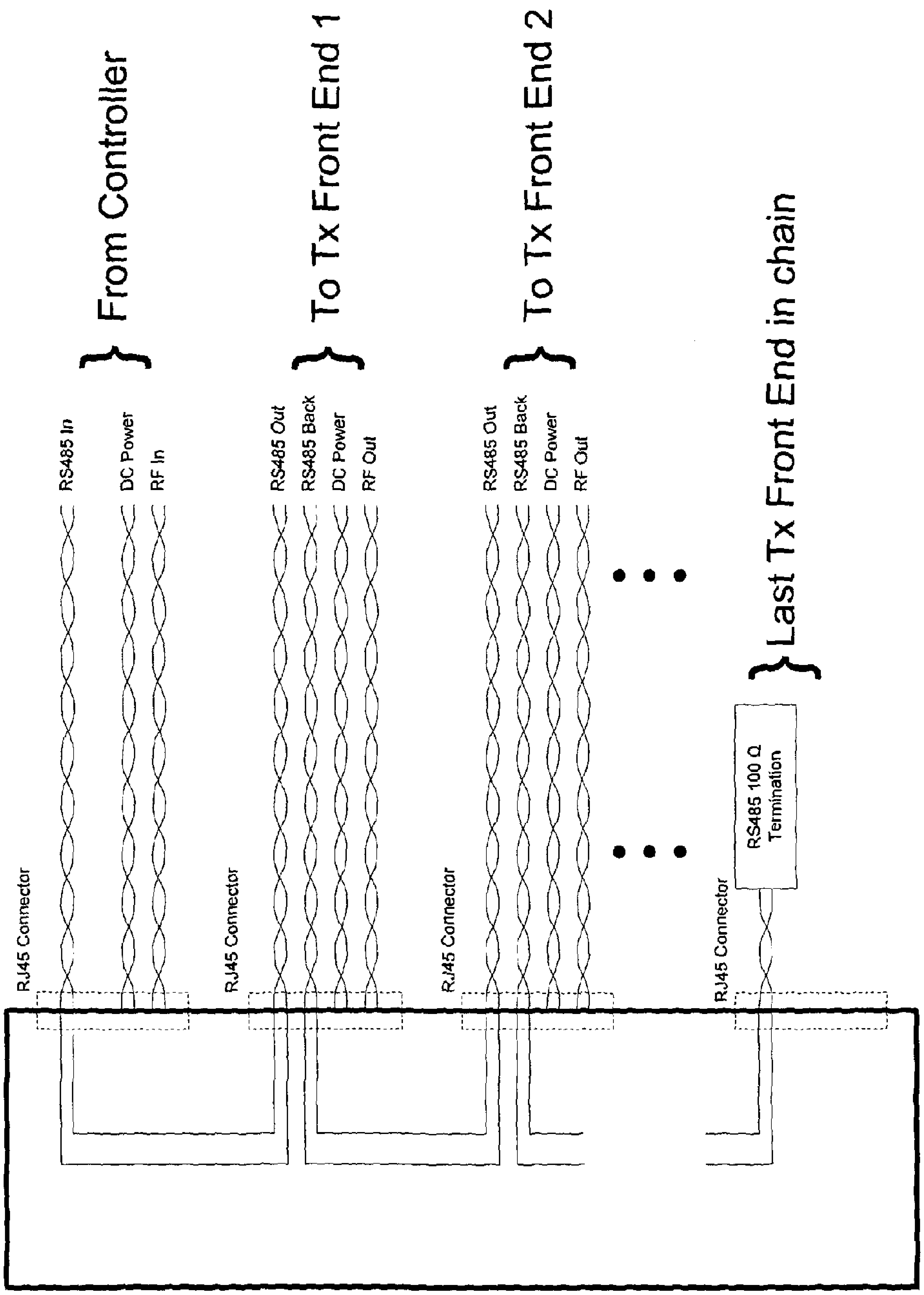

From Controller
RS485 In
DC Power
RF In
To Tx Front End 1
RS485 Out
RS485 Back
DC Power
RF Out
To Tx Front End 2
RS485 Out
RS485 Back
DC Power
RF Out
Last Tx Front End in chain
RS485 100 Ω Termination
RJ45 Connector
RJ45 Connector
RJ45 Connector
RJ45 Connector

Figure 6

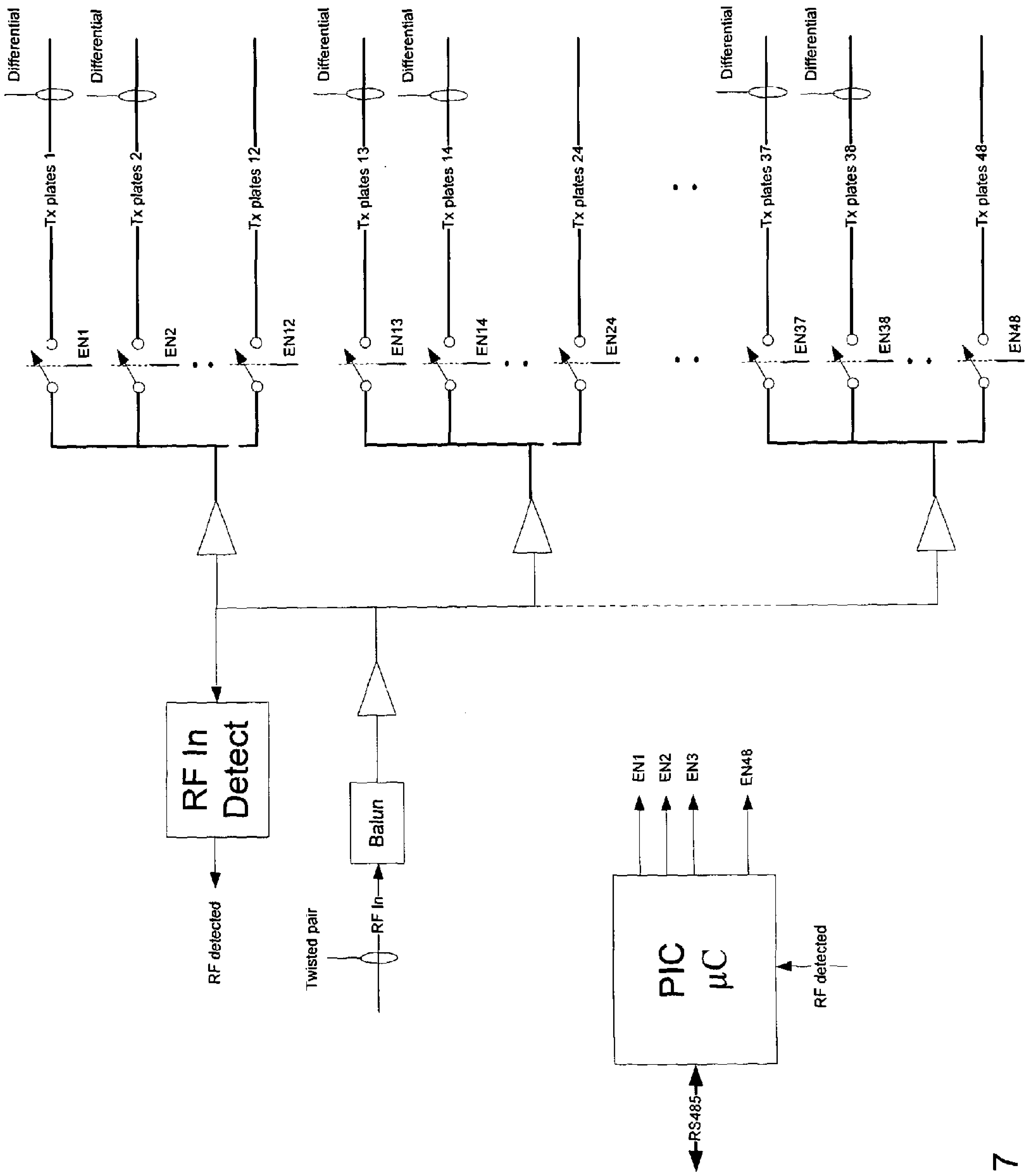

Differential
Tx plates 1
Tx plates 2
Tx plates 12
Tx plates 13
Tx plates 14
Tx plates 24
Tx plates 37
Tx plates 38
Tx plates 48
EN1
EN2
EN12
EN13
EN14
EN24
EN37
EN38
EN48
RF In Detect
RF detected
Balun
RF In
Twisted pair
PIC μC
EN1
EN2
EN3
EN48
RF detected
RS485

Figure 7

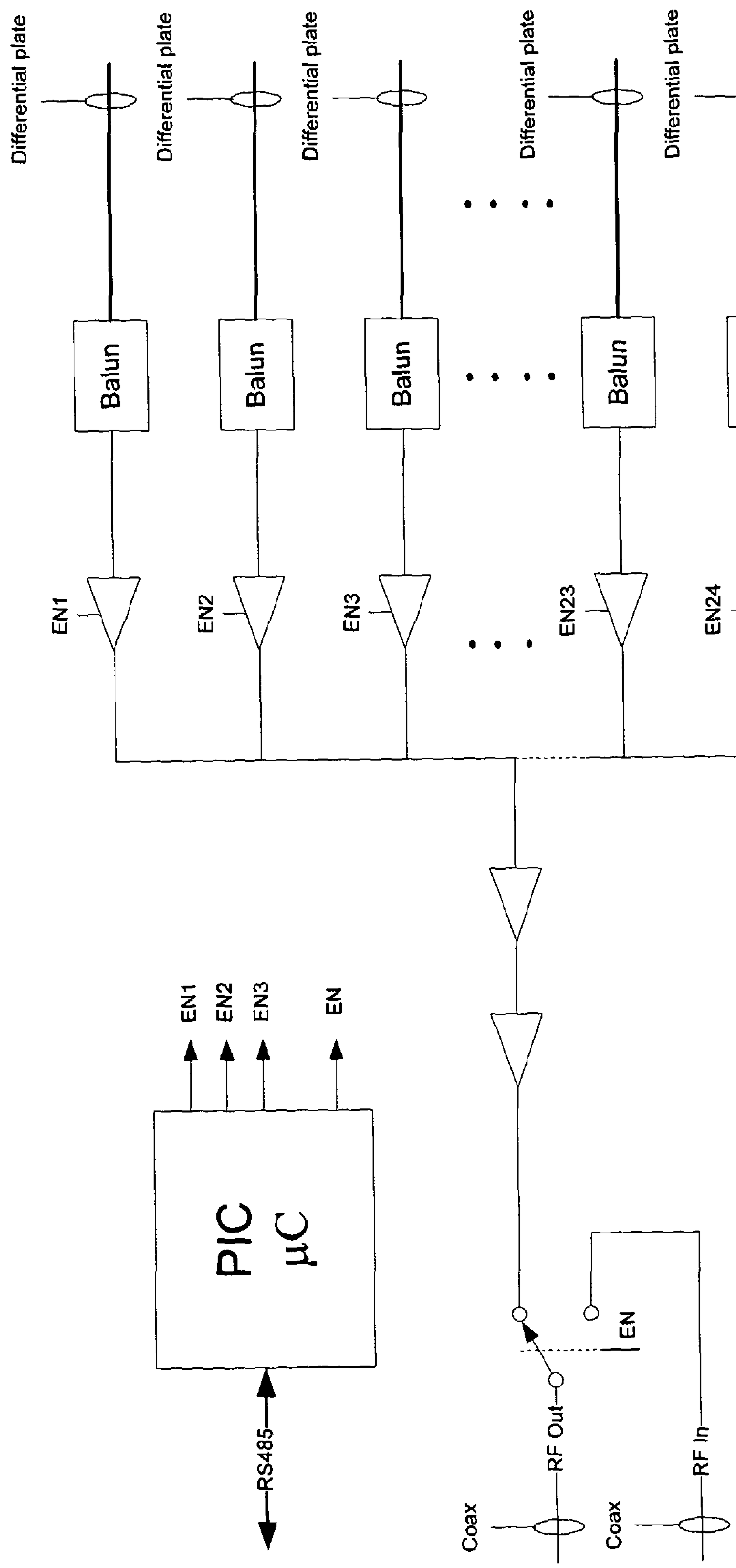

Differential plate
Differential plate
Differential plate
Differential plate
Differential plate
Balun
Balun
Balun
Balun
Balun
EN1
EN2
EN3
EN23
EN24
EN1
EN2
EN3
EN
PIC
μC
RS485
EN
RF Out
RF In
Coax
Coax

Figure 8

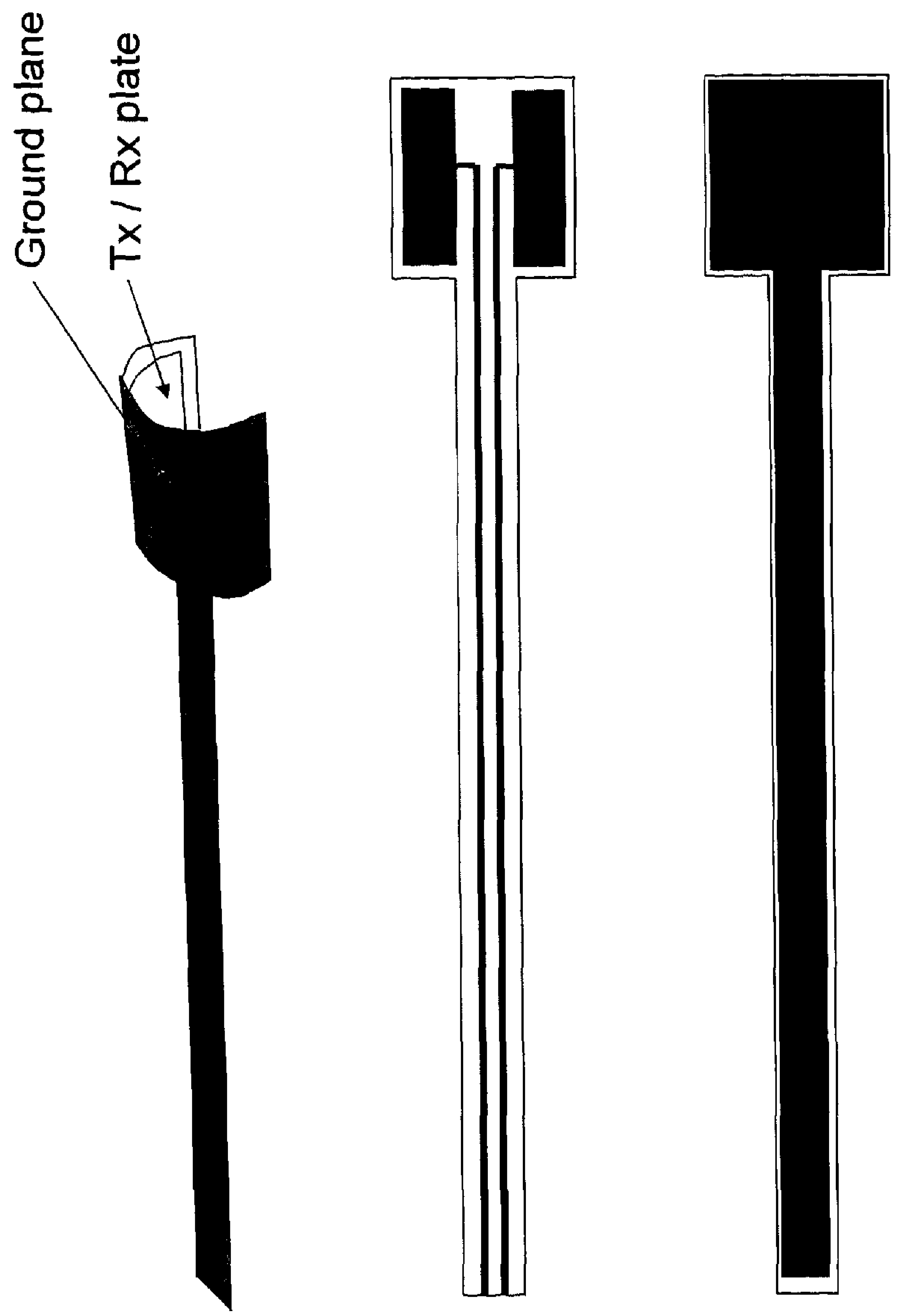


Figure 9 a to c

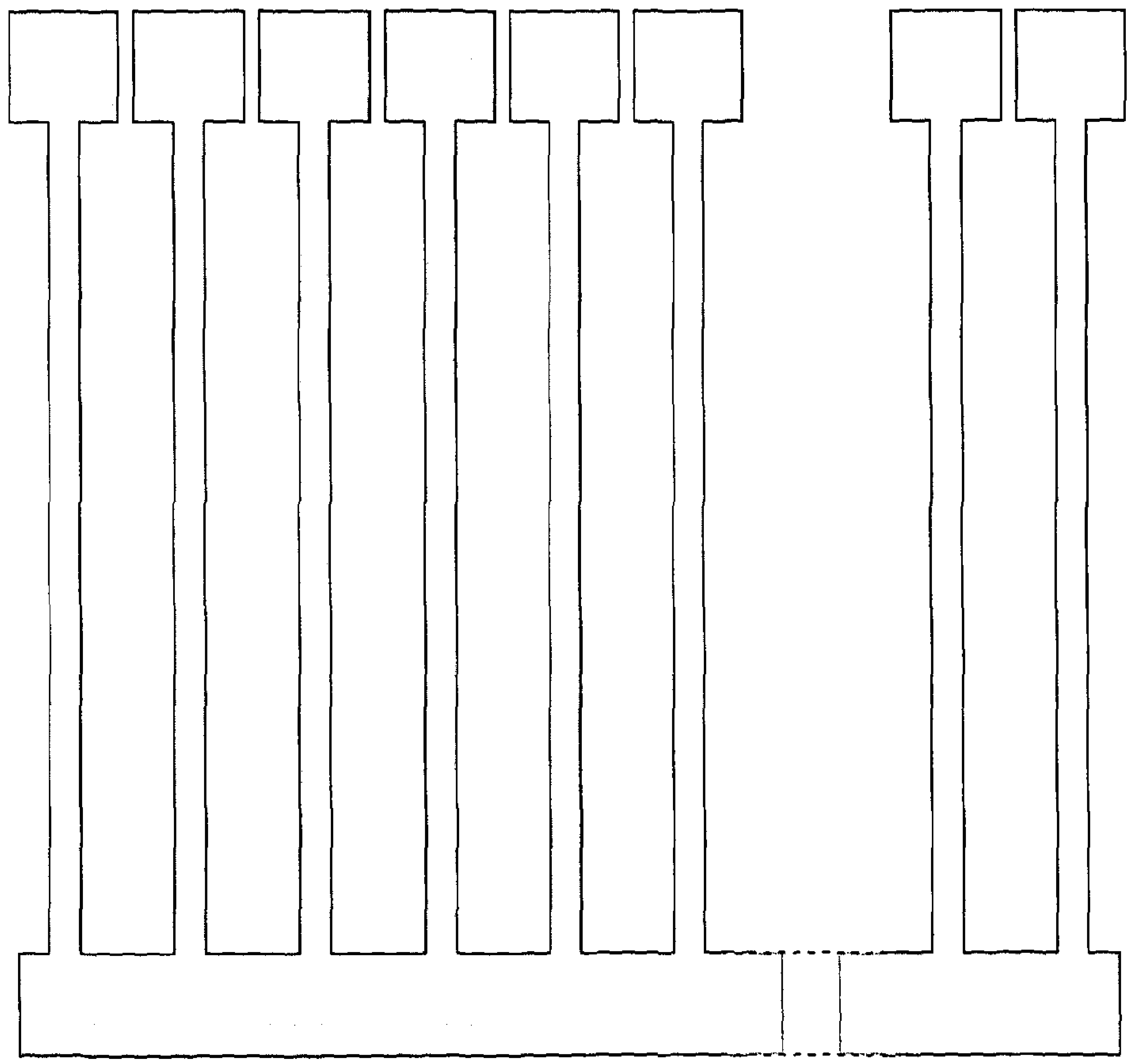


Figure 9d

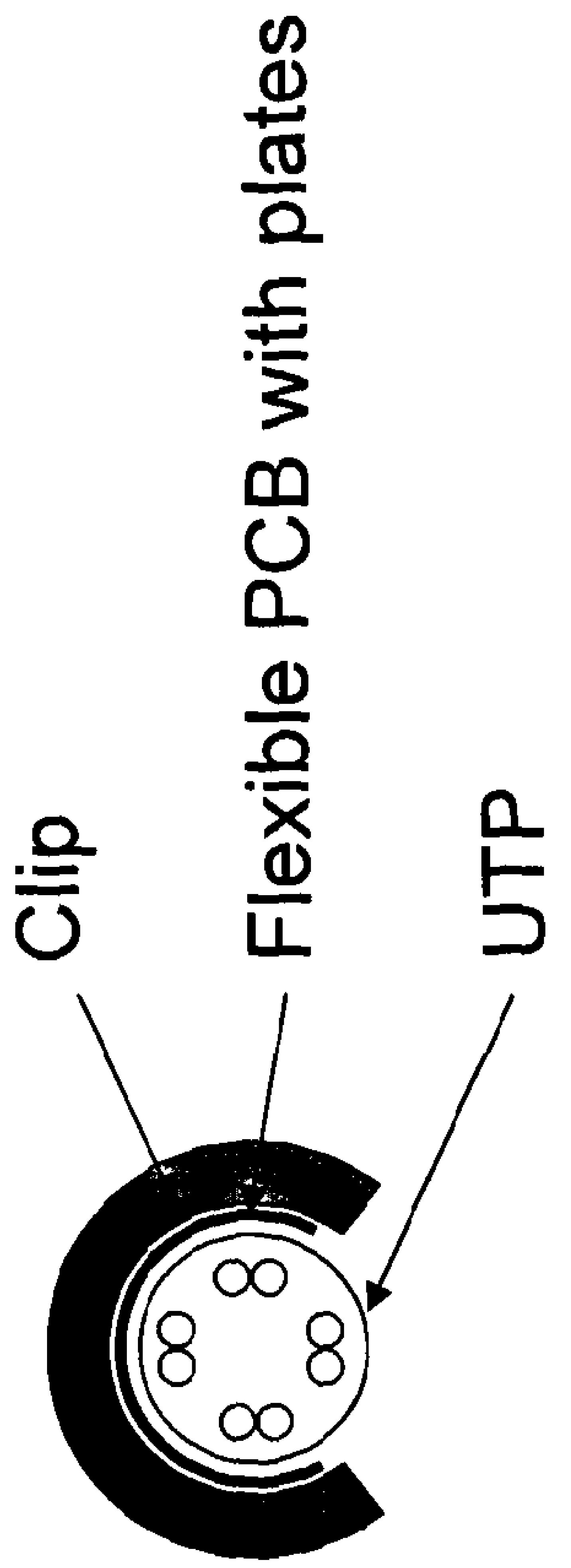


Figure 10

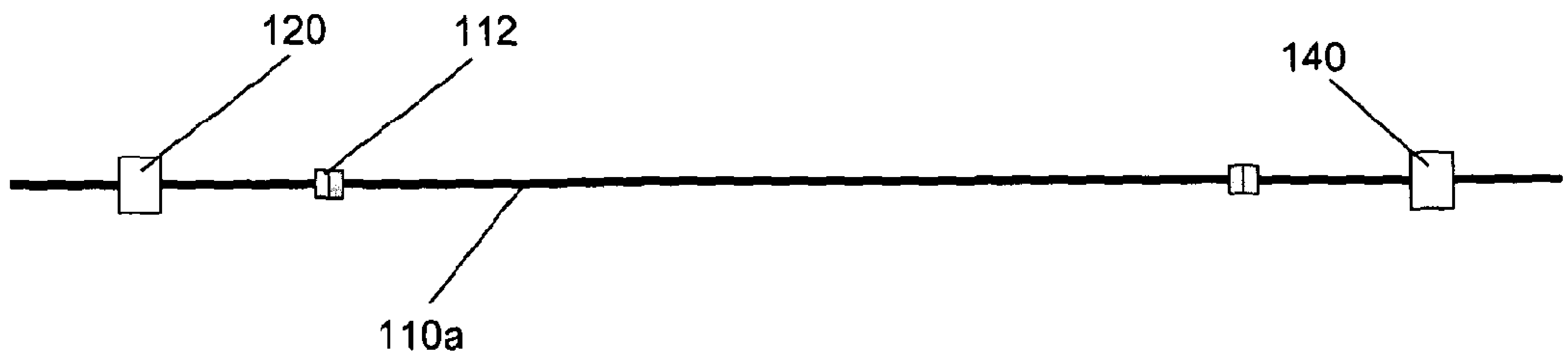


Fig. 11a

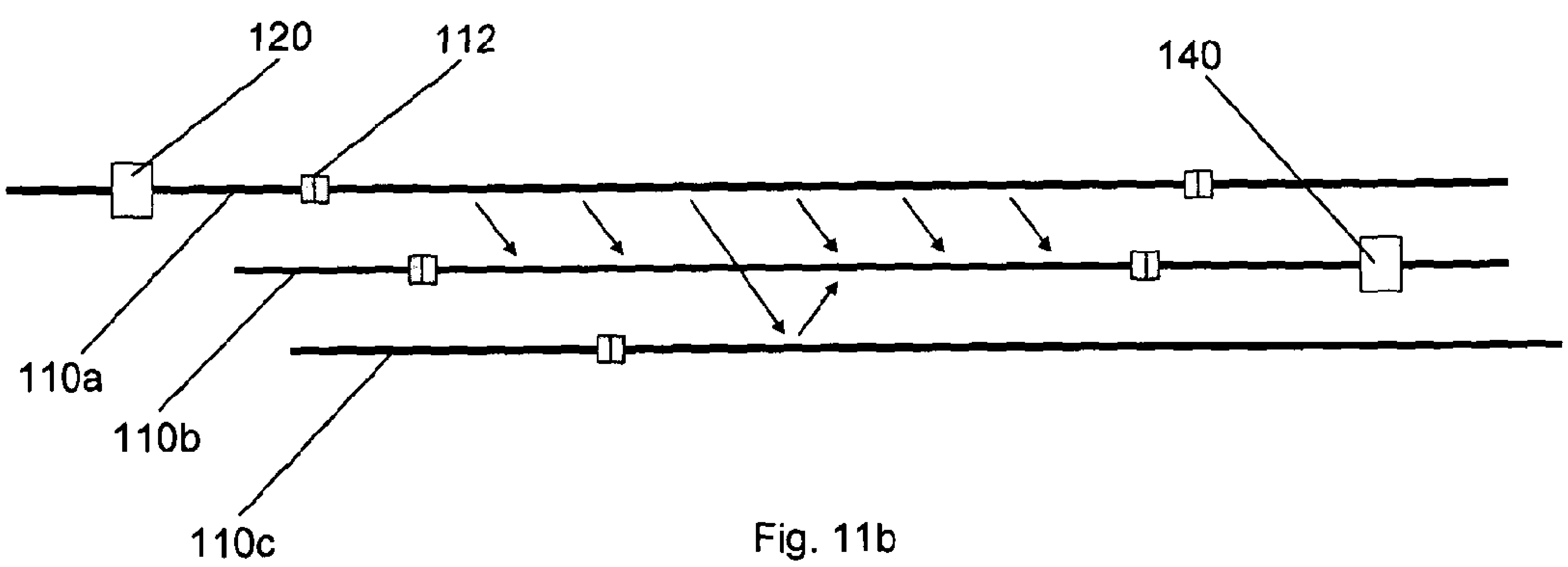
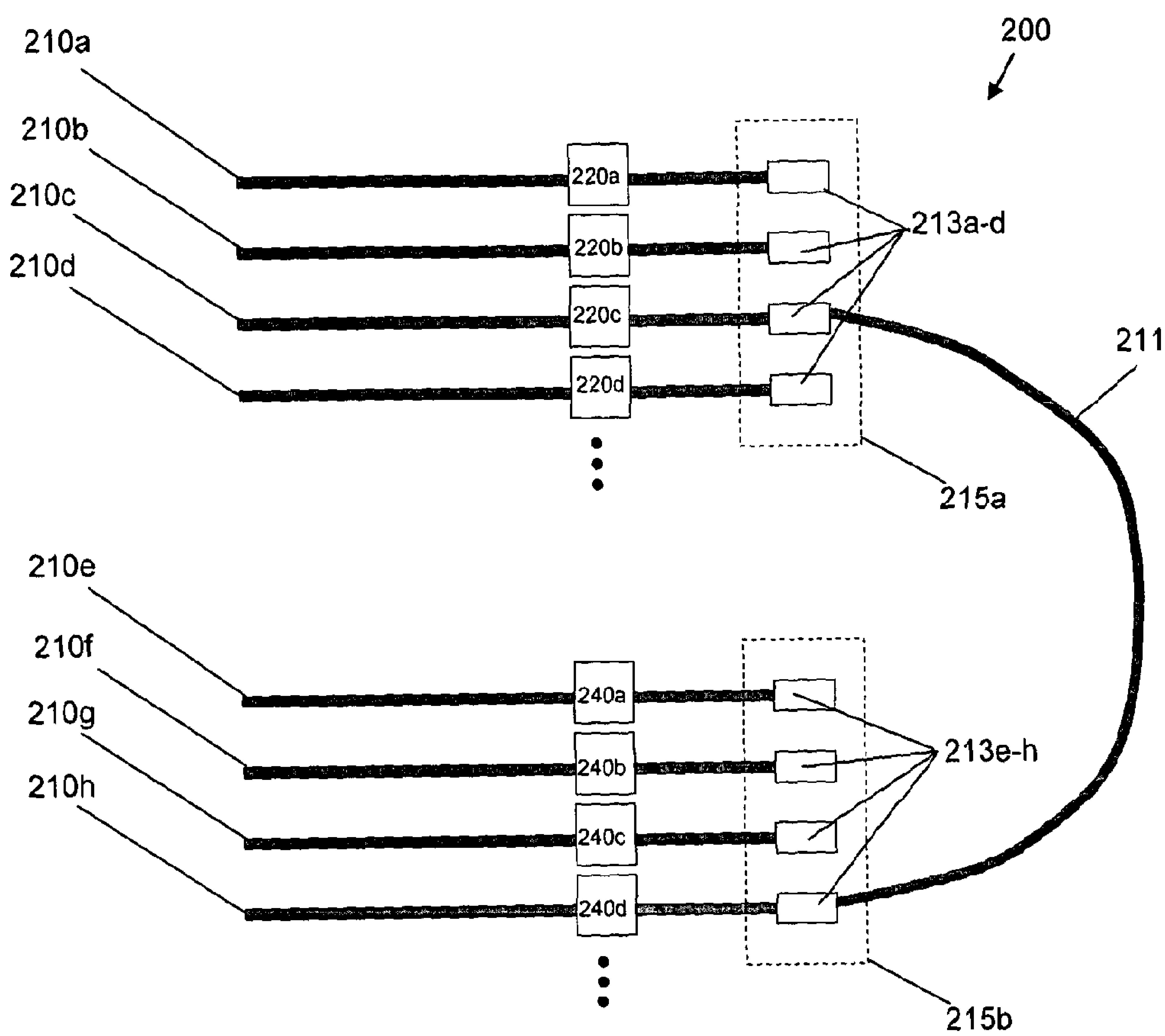


Fig. 11b



200
210a
210b
210c
210d
220a
220b
220c
220d
213a-d
211
215a
210e
210f
210g
210h
240a
240b
240c
240d
213e-h
215b

Fig. 12

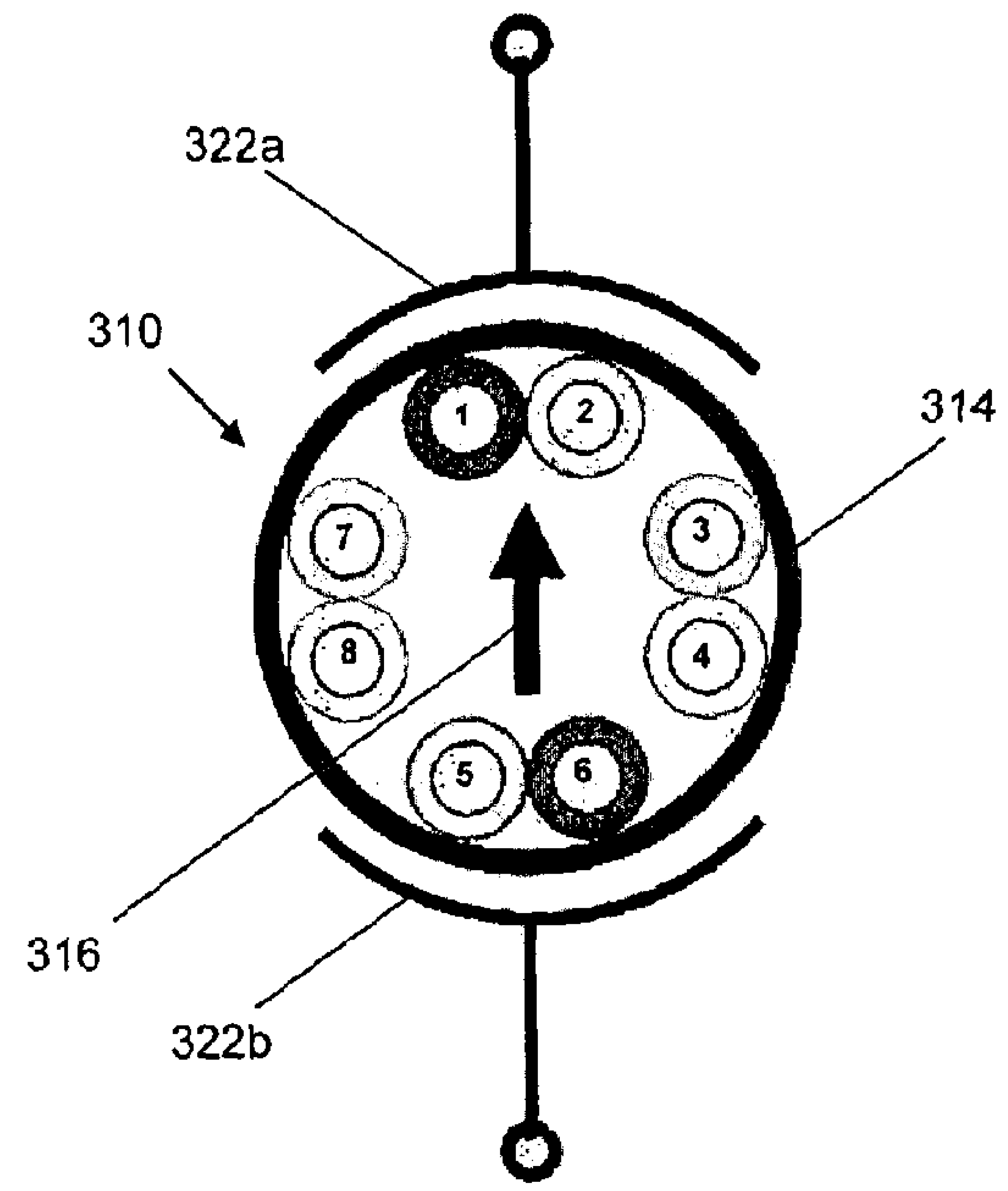


Fig. 13a

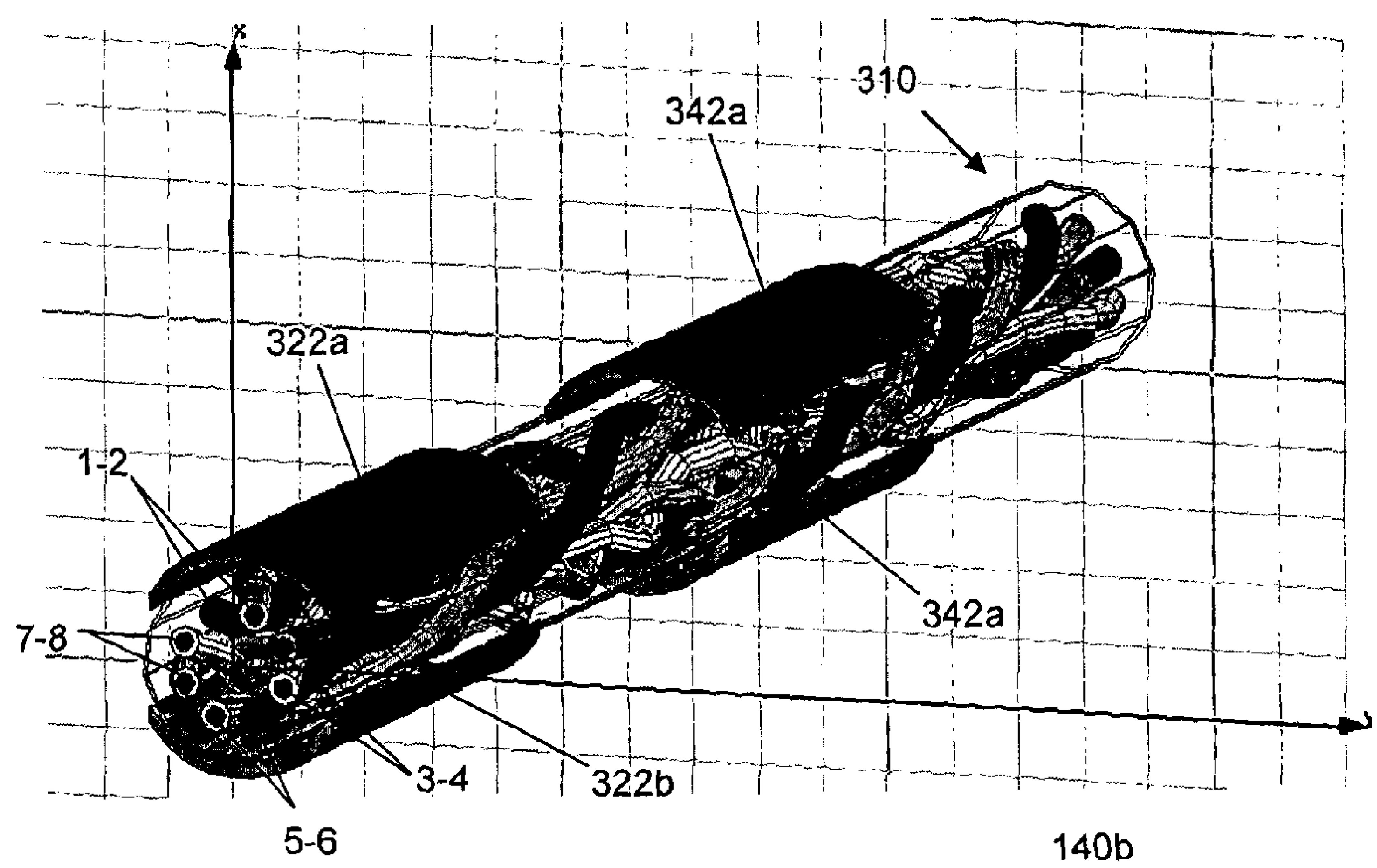


Fig. 13b

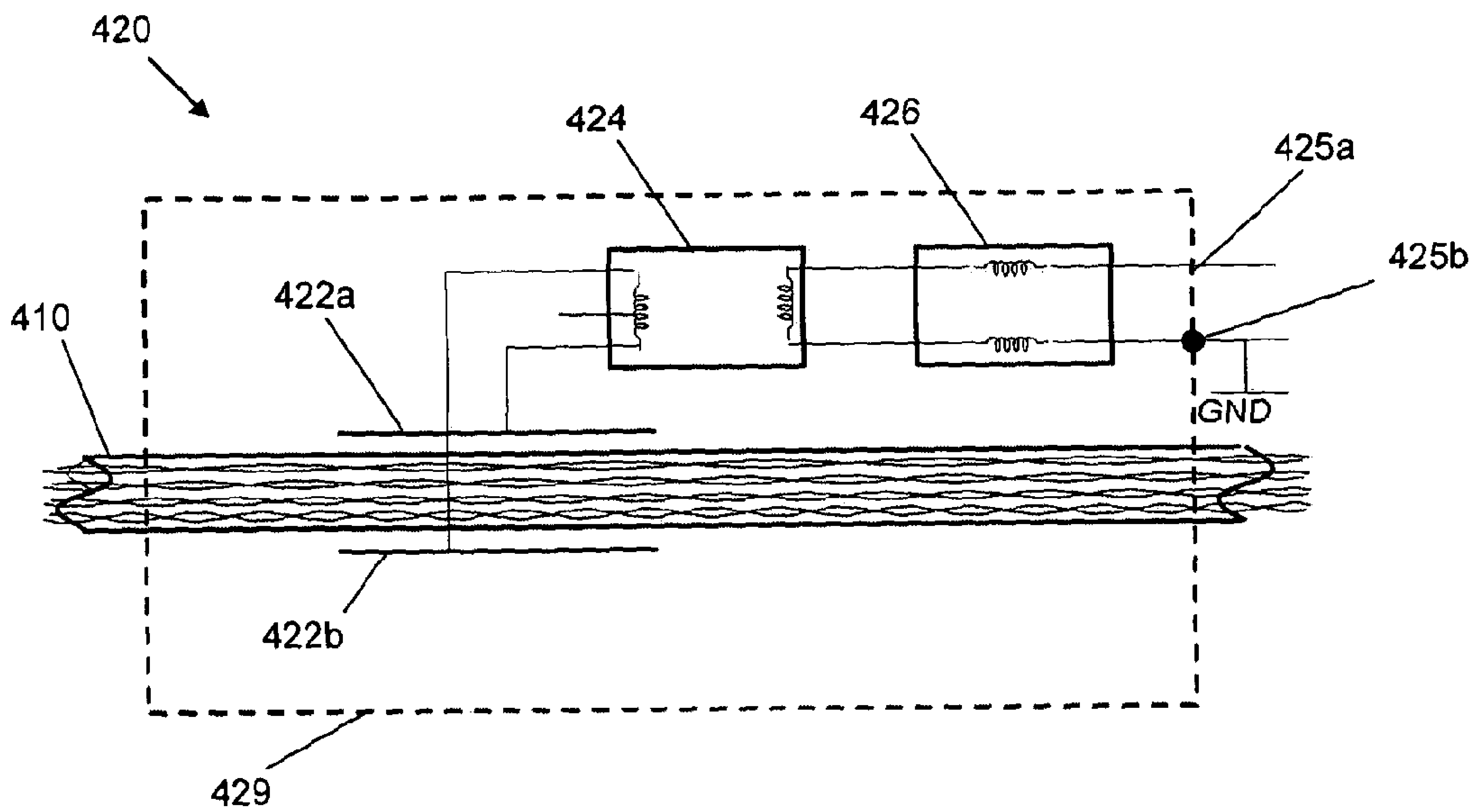


Fig. 14

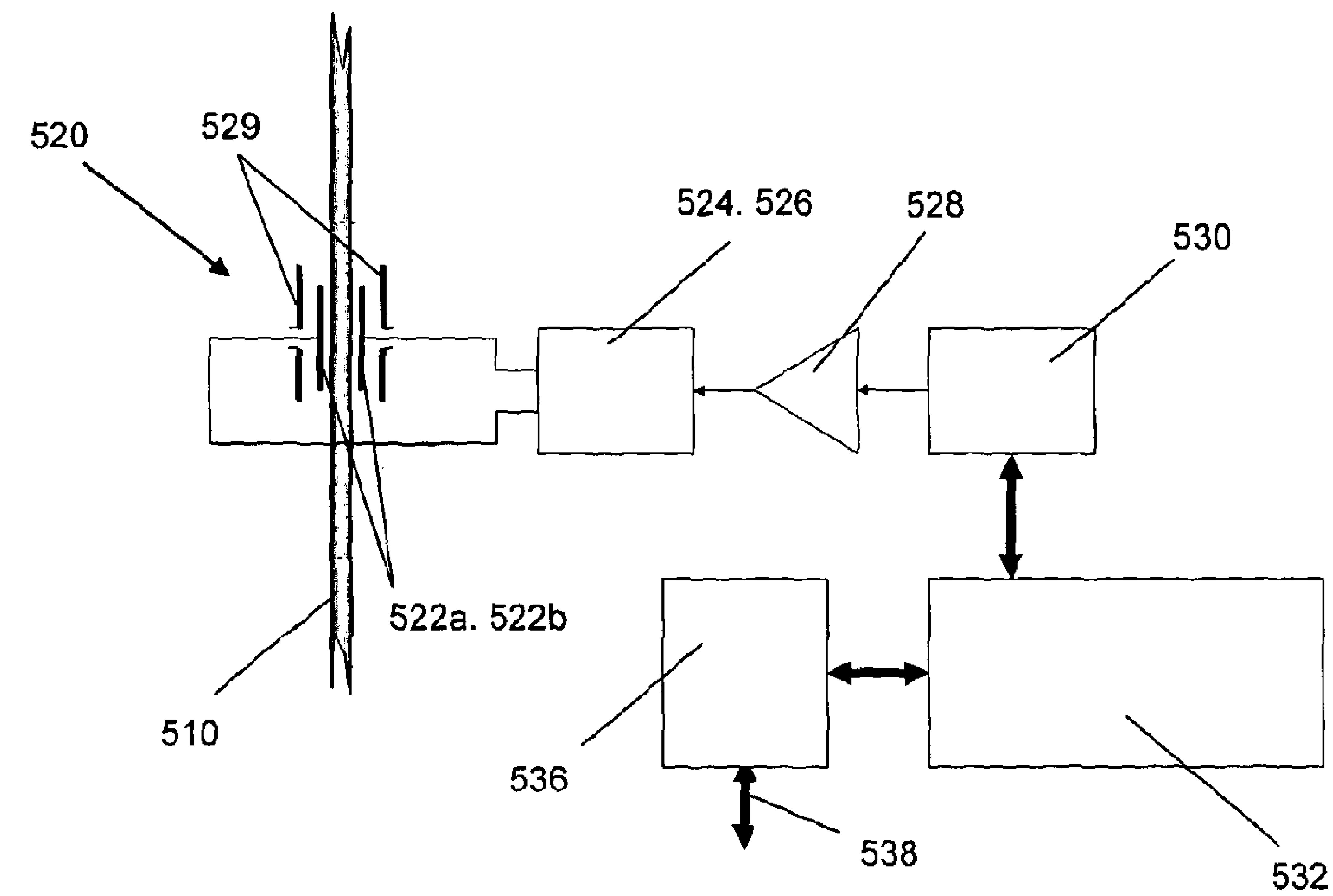


Fig. 15a

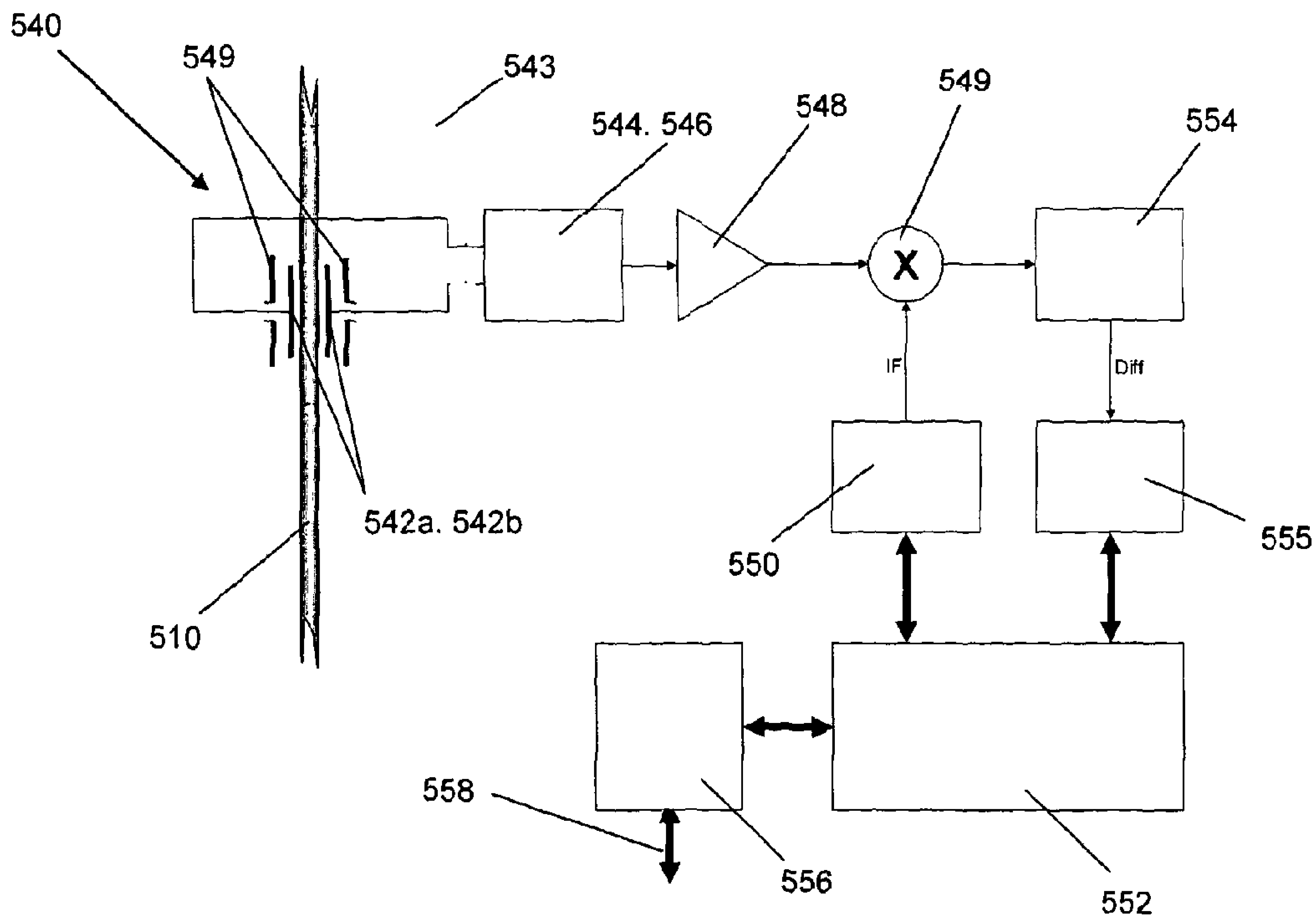


Fig. 15b

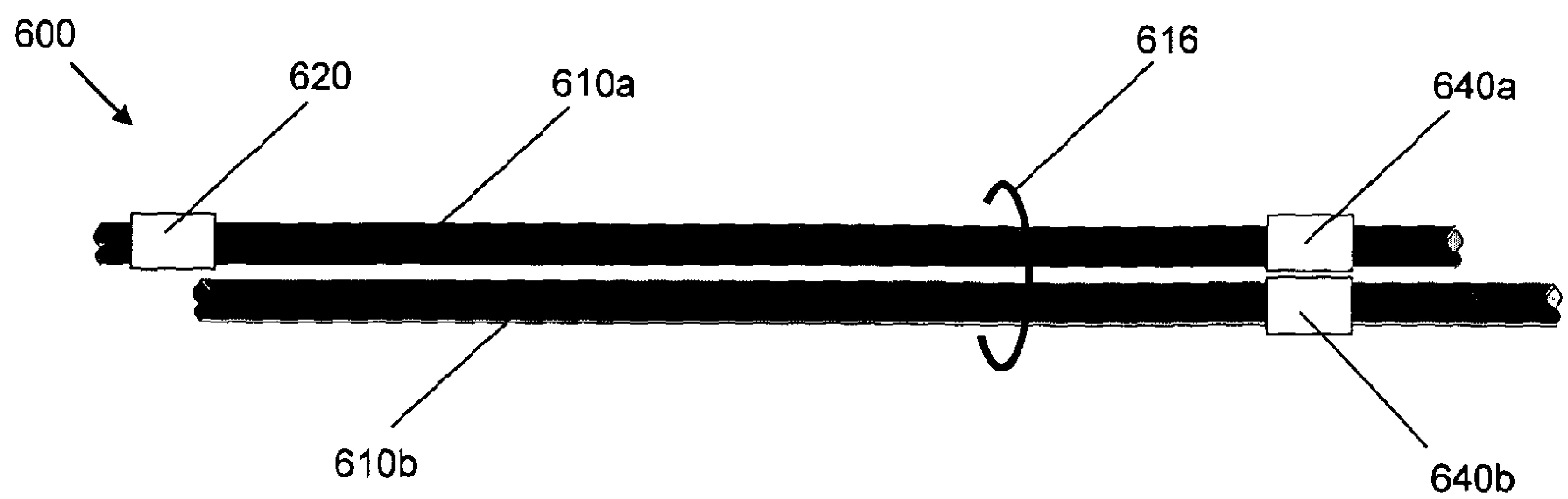


Fig. 16

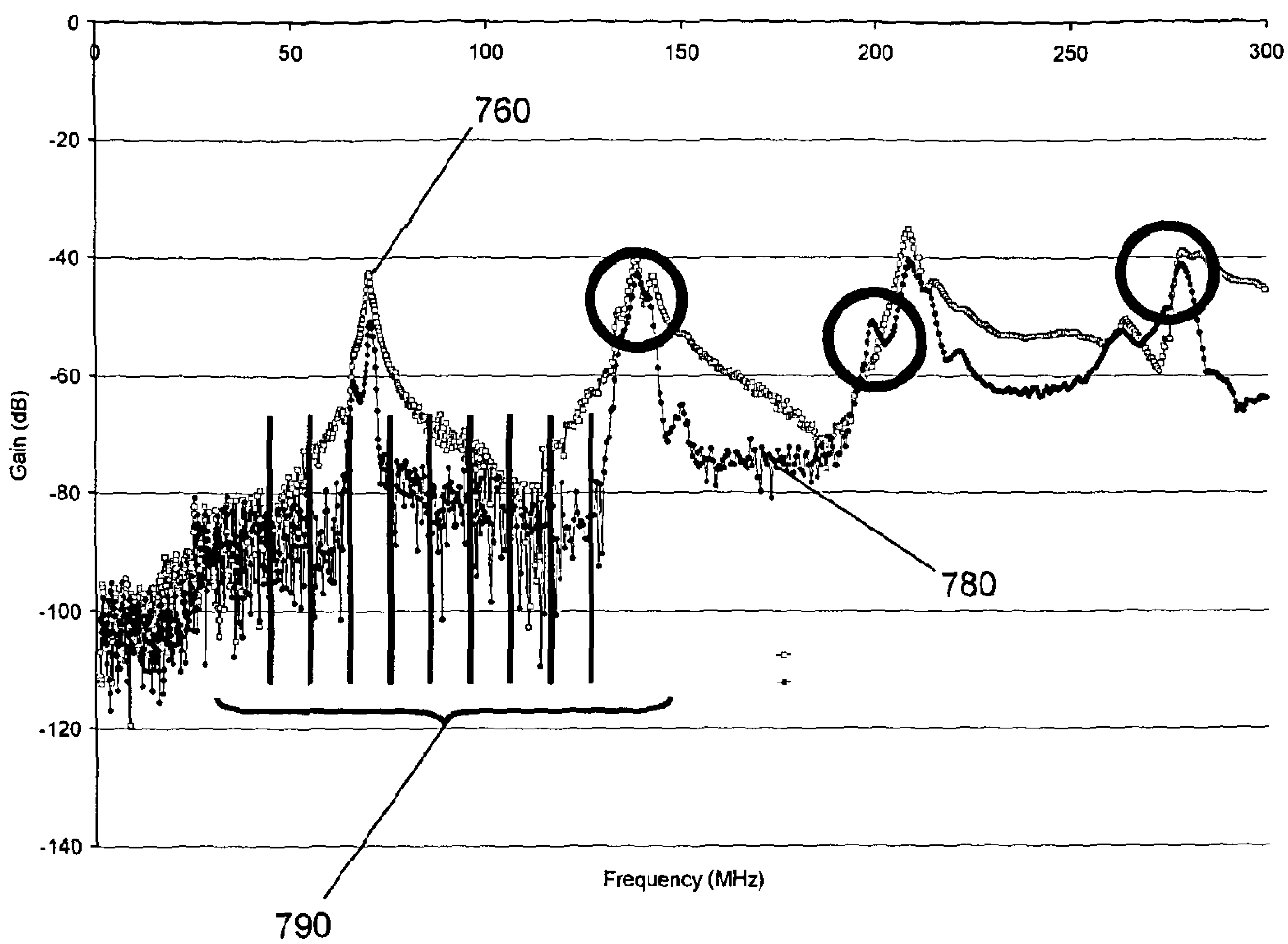

0
-20
-40
-60
-80
-100
-120
-140
0
50
100
150
200
250
300
Gain (dB)
Frequency (MHz)
760
780
790

Fig. 17

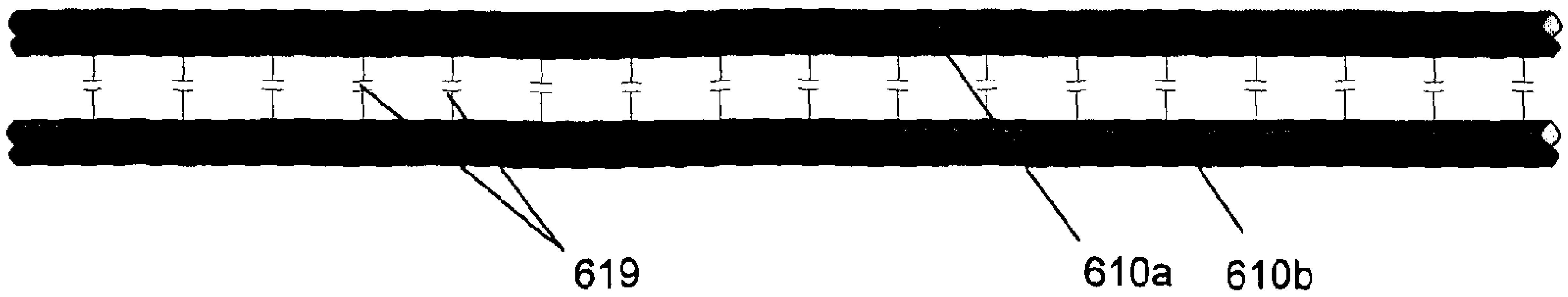


Fig. 18a

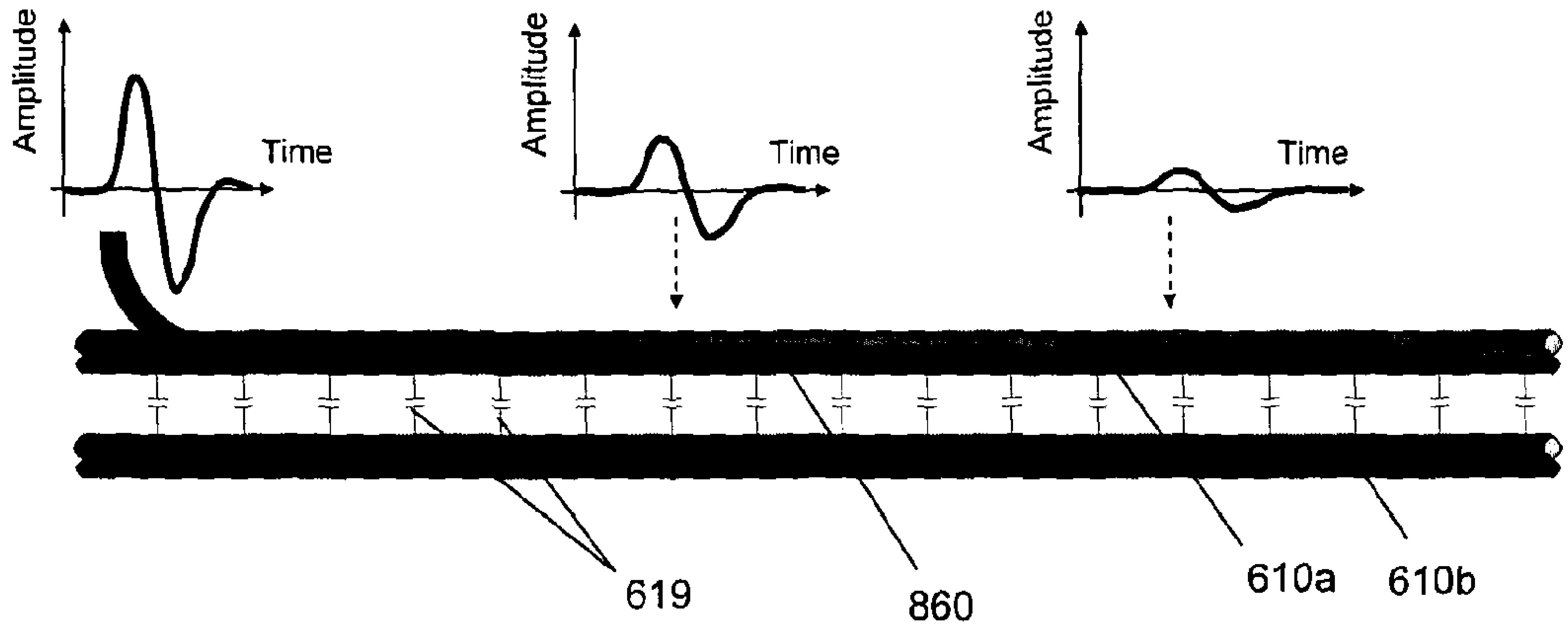


Fig. 18b

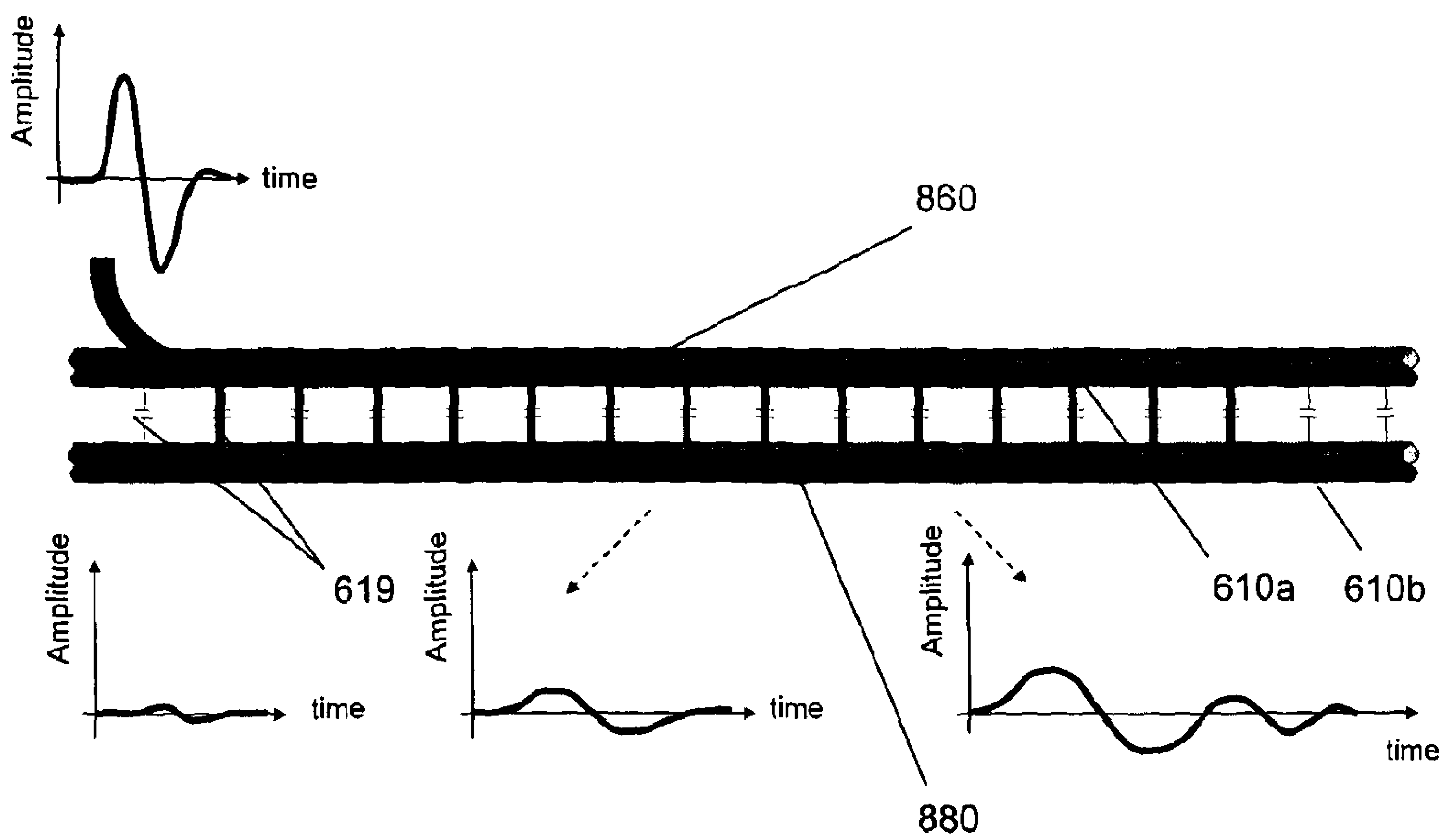


Fig. 18c

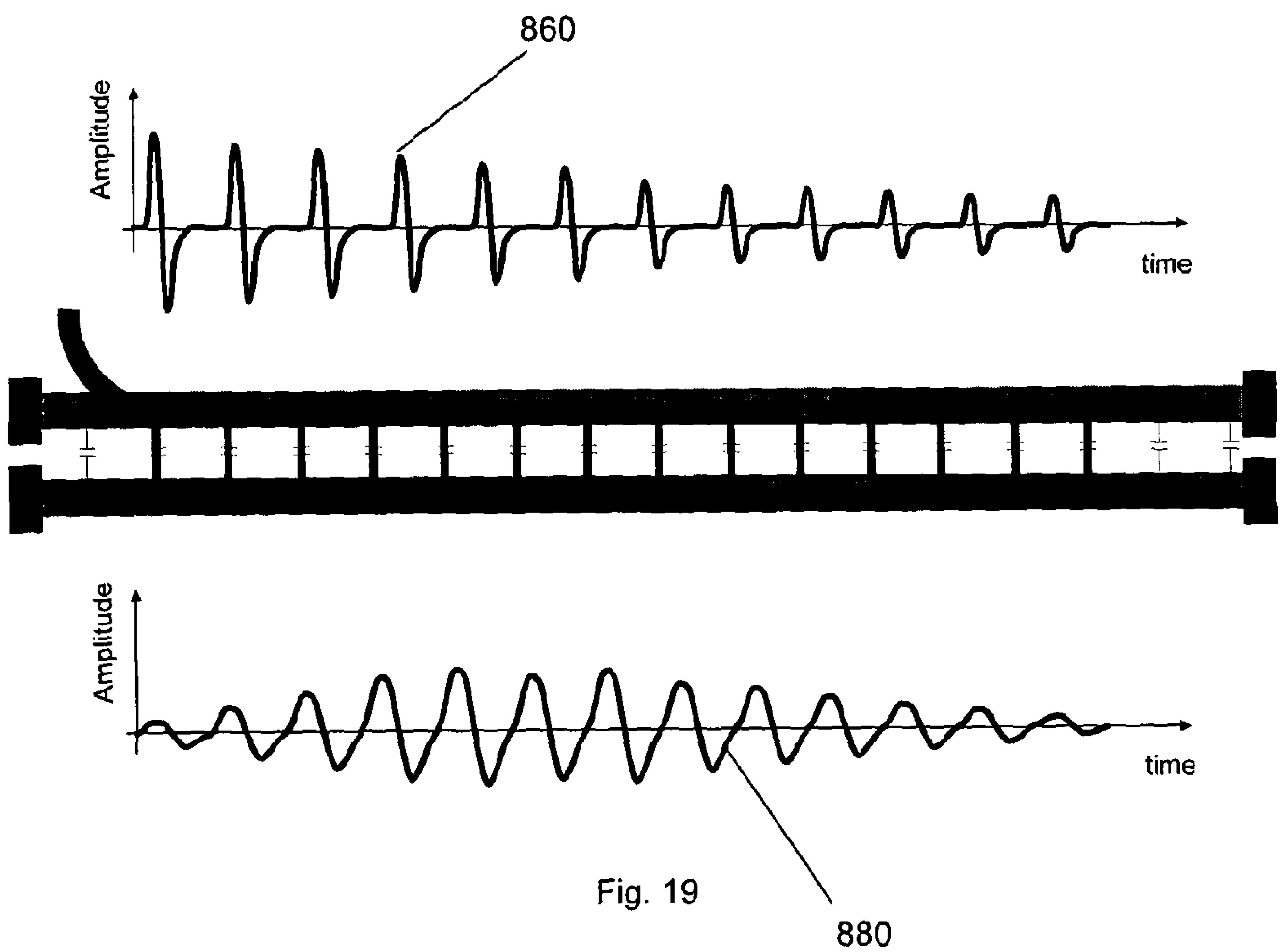


Fig. 19

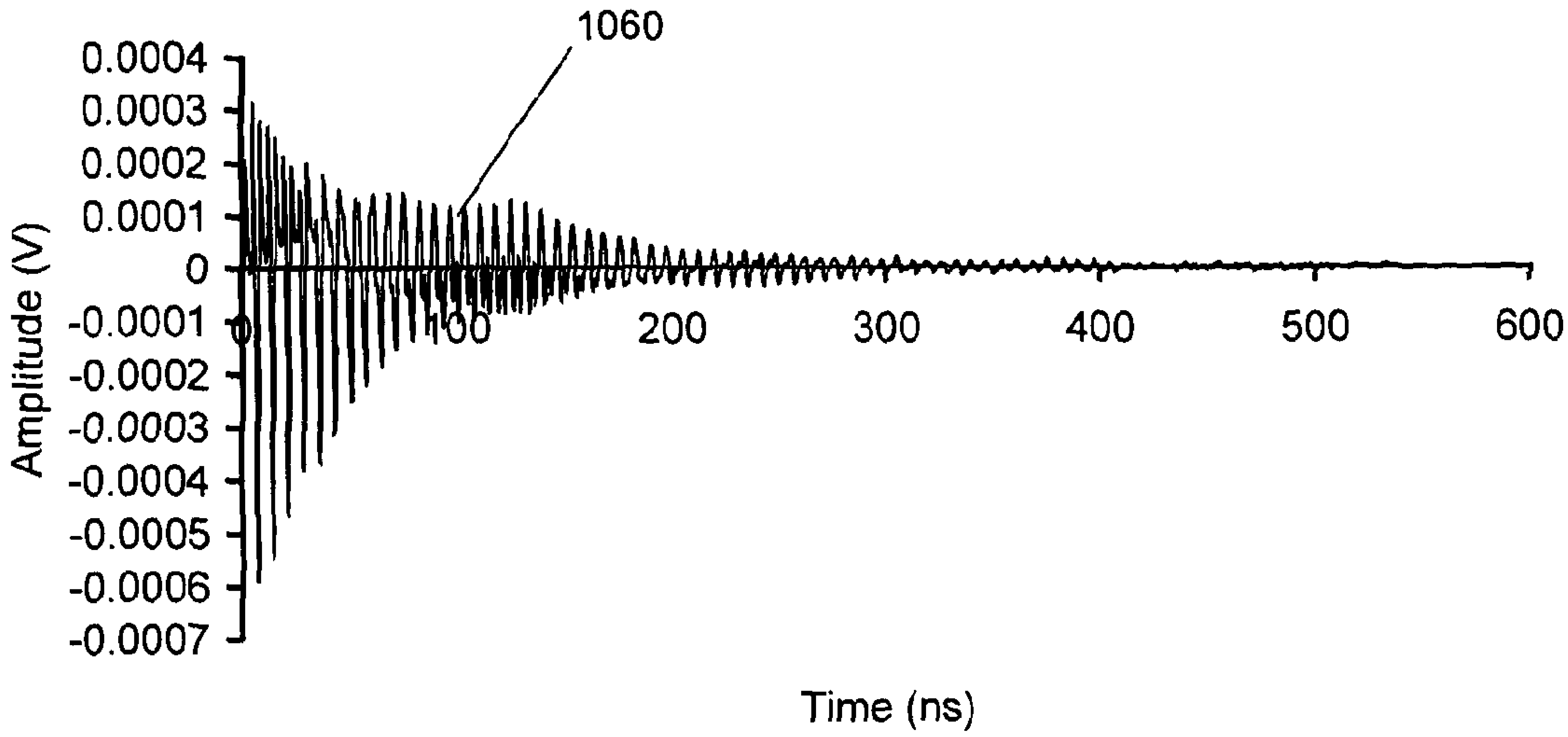


Fig. 20a

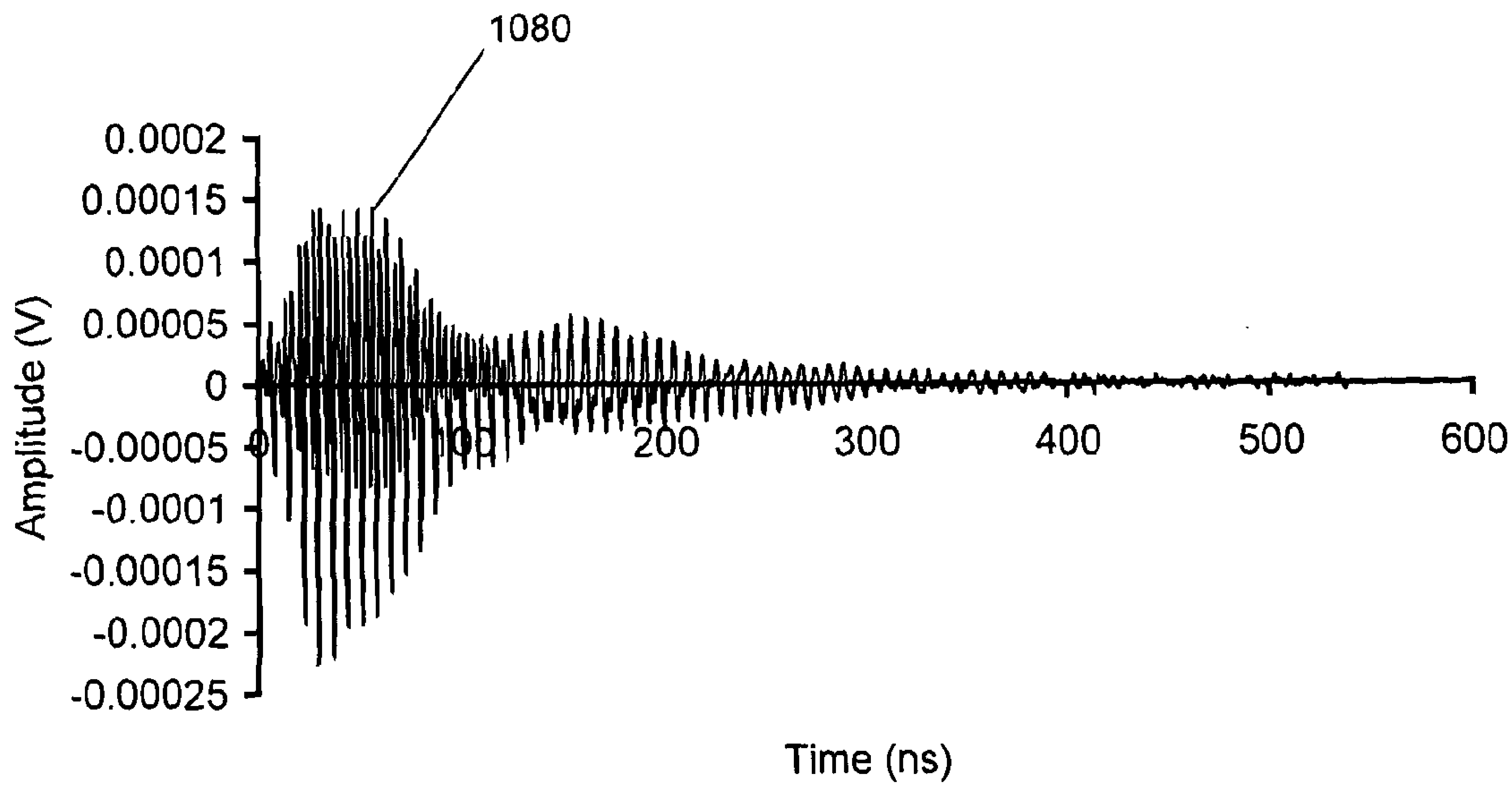


Fig. 20b

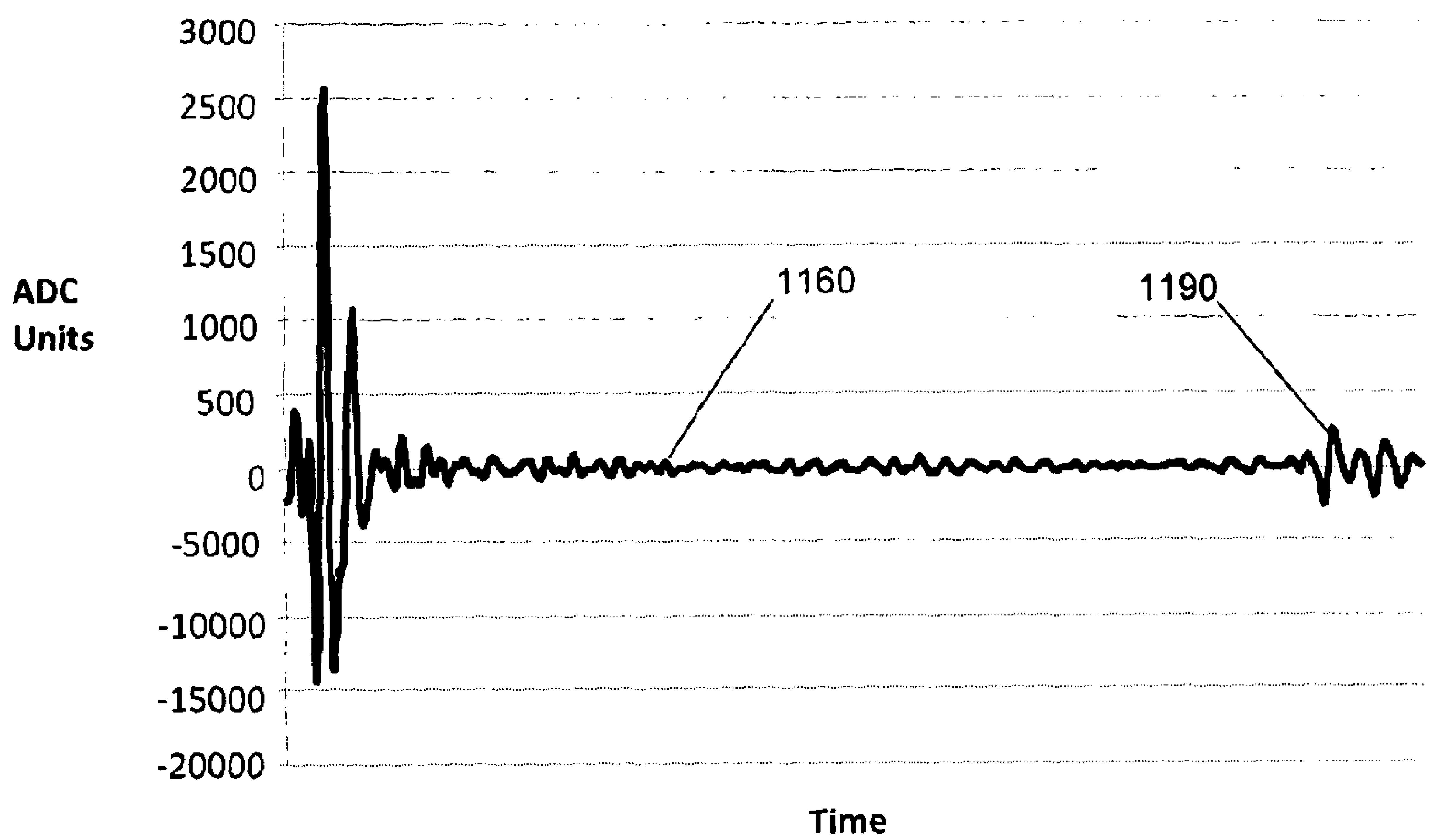


Fig. 21a

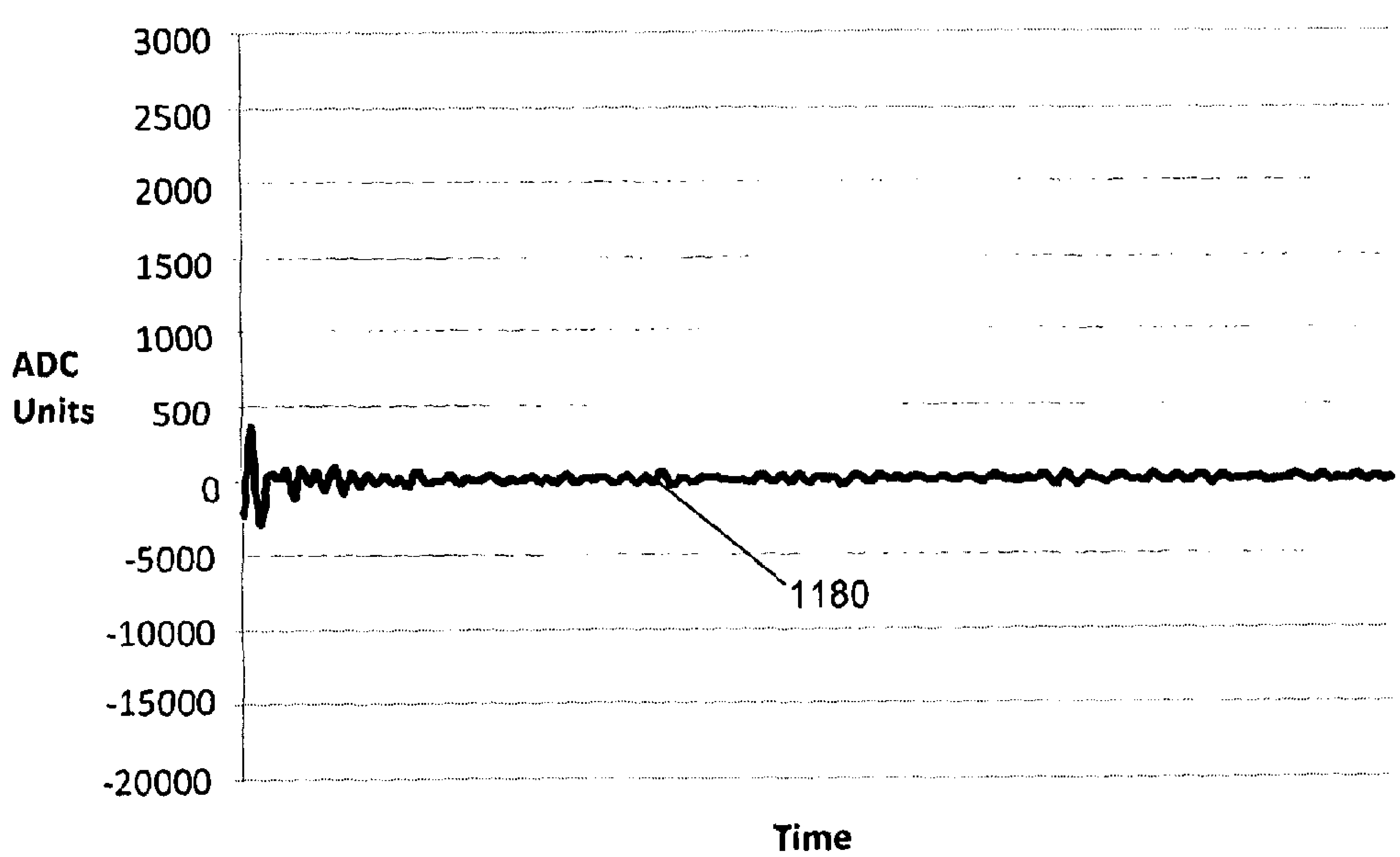


Fig. 21b

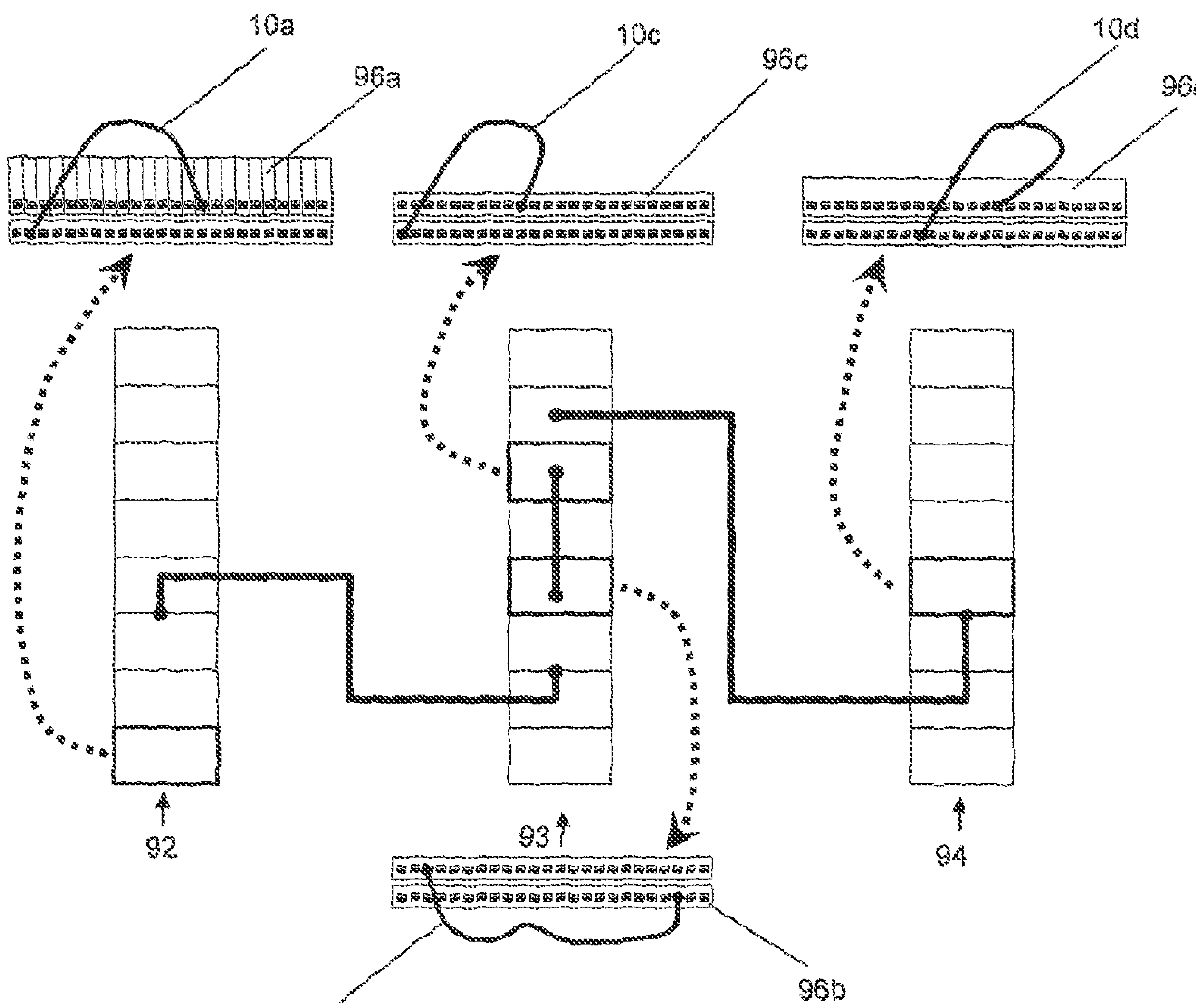


Fig. 22

APPARATUS FOR IDENTIFYING INTERCONNECTIONS AND DETERMINING THE PHYSICAL STATE OF CABLE LINES IN A NETWORK

This invention relates to developments concerning apparatuses for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state (i.e. condition) of cable lines in the network. In some embodiments, this invention may relate to developments concerning apparatuses for both identifying interconnections in a network comprising a plurality of cable lines and for determining the physical state of cable lines in the network. The network may be a local area network, for example.

In some embodiments, test signals are transmitted and received for network inspection purposes. In some embodiments, the test signals are coupled into out from the cable lines of the network using non-contacting coupling units. Analysis of test signals coupled out from the cable lines can used to identify interconnections in the network, e.g. so as to allow a connection map of patch leads to be produced. Analysis of the test signals can also be used be used to determine the physical state (i.e. condition) of cable lines in the network, e.g. so as to ensure that network data traffic can propagate correctly.

Cables which include a plurality of twisted pairs, referred to as "twisted pair cables" herein, are well known. Such cables are commonly used for telecommunications purposes, e.g. computer networking and telephone systems. In the field of telecommunications, twisted pair cables are usually provided without shielding, as unshielded twisted pair (UTP) cables. However, shielded twisted pair (STP) cables are also known.

In this context, a "twisted pair" is a pair of conductors, usually a forward conductor and a return conductor of a single circuit, which have been twisted together. The conductors are usually twisted together for the purposes of cancelling out electromagnetic interference from external sources and to minimise crosstalk between neighbouring twisted pairs within a cable comprising a plurality of twisted pairs. In this way, each twisted pair provides a reliable respective communication channel for a signal, usually a differential voltage signal, to be conveyed within the twisted pair. Common forms of unshielded twisted pair (UTP) cables are category 5 and category 6 UTP cables which include eight conductors twisted together in pairs to form four twisted pairs.

The design and construction of twisted pair cables is carefully controlled by manufacturers to reduce noise due to electromagnetic interference and to reduce crosstalk between the twisted pairs within the cables. To this end, each twisted pair in a twisted pair cable normally has a different twist rate (i.e. number of twists per unit length along the cable) from that of the other twisted pairs in the twisted pair cable. It is also usual for the twisted pairs to be twisted around each other within the cable. Fillets or spacers may be used to separate physically the twisted pairs.

Networks including ports interconnected by a plurality of cables, such as local area networks (LANs), are also well known. LANs are typically used to enable equipment such as computers, telephones, printers and the like to communicate with each other and with remote locations via an external service provider. LANs typically utilise twisted pair network cables, usually in the form of UTP cables.

The cables used in LANs are typically connected to dedicated service ports throughout one or more buildings. The cables from the dedicated service ports can extend through the walls, floor and/or ceilings of the building to a communications hub, typically a communications room containing a number of network cabinets. The cables from wall and floor sockets within the building and from an external service provider are also usually terminated within the communications room.

A "patch system" may be used to interconnect various ports of the LAN within the network cabinets. In a patch system, all cable lines in the LAN can be terminated within the network cabinets in an organized manner. The terminations of the cable lines in the network are provided by the structure of the network cabinets, which are typically organised in a rack system. The racks contain "patch panels", which themselves utilise sets of ports, typically RJ-45 type connector ports, at which the cable lines terminate.

Each of the ports in each patch panel is hard wired to one of the cable lines in the LAN. Accordingly, each cable line is terminated on a patch panel in an organized manner. In small patch systems, all cable lines in the LAN may terminate on the patch panels of the same rack. In larger patch systems, multiple racks are used, wherein different cable lines terminate on different racks.

Interconnections between the various ports in the LAN are typically made using "patch cables", which are usually UTP cables including four twisted pairs. Each end of a patch cable is terminated by a connector, such as an RJ-45 type connector for inserting into an RJ-45 type connector port. One end of each patch cable is connected to the port of a first cable line and the opposite end of the patch cable is connected to the port of a second cable line. By selectively connecting the various cable lines using the patch cables, a desired combination of network interconnections can be achieved.

FIG. **1** shows a typical patch system organised into a server row, a cross-connect row and a network row, which include patch panels. Patch cables are used to interconnect two ports through the patch system.

In many businesses, employees of a company are assigned their own computer network access number so that the employee can interface with the company's IT infrastructure. When an employee changes office locations, it is not desirable to provide that employee with newly addressed port in the network. Rather, to preserve consistency in communications, it is preferred that the exchanges of the ports in the employee's old office be transferred to the telecommunications ports in the employee's new location. This type of move is relatively frequent. Similarly, when new employees arrive and existing employees depart, it is usually necessary for the patch cables in the network cabinet(s) to be rearranged so that each employee's exchanges can be received in the correct location.

As the location of employees change, the patch cables in a typical cabinet are often manually entered in a computer based log. This is burdensome. Further, technicians often neglect to update the log each and every time a change is made. Accordingly, the log is often less than 100% accurate and a technician has no way of reading where each of the patch cables begins and ends. Accordingly, each time a technician needs to change a patch cable, that technician manually traces that patch cable between an internal line and an external line. To perform a manual trace, the technician locates one end of a patch cable. The technician then manually follows the patch cable until he/she finds the opposite end of that patch cable. Once the two ends of the patch cable are located, the patch cable can be positively identified.

It takes a significant amount of time for a technician to manually trace a particular patch cable, especially in large patch systems. Furthermore, manual tracing is not completely accurate and a technician may accidently go from one patch cable to another during a manual trace. Such errors result in misconnected patch cables which must be later identified and corrected.

Attempts have been made in the prior art to provide an apparatus which can automatically trace the common ends of each patch cable within local area networks, thereby reducing the labour and inaccuracy of manual tracing procedures.

For example, U.S. Pat. No. 5,483,467 describes a patching panel scanner for automatically providing an indication of the connection pattern of the data ports within a LAN, so as to avoid the manual task of identifying and collecting cable connection information. In one embodiment, which is intended for use with shielded twisted pair cables, the scanner uses inductive couplers which are associated with the data ports. The inductive coupler is disclosed as being operative to impose a signal on the shielding of shielded network cables in order to provide an indication of the connection pattern produced by connection of the cables to a plurality of ports.

In another embodiment of U.S. Pat. No. 5,483,467, the scanner is coupled to each data port by "dry contact" with a dedicated conductor in a patch cable. This is difficult to implement in practice, because most network cables have to meet a particular pre-determined standard in the industry, such as the RJ-45 type standard, in which there is no free conductor which could be used for determining interconnectivity.

U.S. Pat. No. 6,222,908 discloses a patch cable identification and tracing system in which the connectors of each patch cable contain a unique identifier which can be identified by a sensor in the connector ports of a telecommunications closet. By reading the unique identifier on the connectors of each patch cable, the system can keep track of which patch chords are being added to and removed from the system. Although this system avoids the use of dedicated conductors in the patch cable, it is difficult to implement because it requires use of non-standard patch cables, i.e. patch cables with connectors containing unique identifiers.

International Patent Application Publication Number WO00/60475 discloses a system for monitoring connection patterns of data ports. This system uses a dedicated conductor which is attached to the external surface of a network cable in order to monitor the connection pattern of data ports. Although this allows the system to be used with standard network cables, it still requires the attaching of dedicated conductors to the external surfaces of network cables and adapter jackets which are placed over the standard network cable.

U.S. Pat. No. 6,285,293 discloses another system and method for addressing and tracing patch cables in a dedicated telecommunications system. The system includes a plurality of tracing interface modules that attach to patch panels in a telecommunications closet. On the patch panels, are located a plurality of connector ports that receive the terminated ends of patch cables. The tracing interface modules mount to the patch panels and have a sensor to each connector port which detects whenever a patch cable is connected to the connector port. A computer controller is connected to the sensors and monitors and logs all changes to the patch cable interconnections in an automated fashion. However, this system cannot be retrofitted to an existing network and relies on the operator to work in a particular order if the patch cable connections are to be accurately monitored.

International Patent Application Publication Number WO2005/109015, which relates to the field of cable state testing, discloses a method of determining the state of a cable comprising at least one electrical conductor and applying a generated test signal to at least one conductor of the cable by a non-electrical coupling transmitter. The reflected signal is then picked up and compared with expected state signal values for the cable, so that the state of the cable can be determined. The present inventors have found that signals coupled to a twisted pair cable by the methods described in WO2005/109015 have a tendency to leak out from the twisted pair cable, especially when other twisted pair cables are nearby.

GB2468925, US2011/0181374 and WO2010/109211, by the present inventors, and the content of which is herewith incorporated in its entirety, each describe apparatuses and methods for coupling a signal to and from a twisted pair cable by non-contact coupling with twisted pairs in the twisted pair cable, such that the signal propagates along the cable between at least two of the twisted pairs. Such signals may be used to determine interconnections, e.g. within a local area network. These patent applications generally relates to a discovery that a twisted pair cable, e.g. an unshielded twisted pair (UTP) cable, provides communication channels which are additional to the respective communication channel provided within each twisted pair in the cable. In particular, it has been found that additional communication channels exist between each combination of two twisted pairs within a twisted pair cable, due to coupling between the twisted pairs. Each combination of two twisted pairs within a twisted pair cable has been termed a "pair-to-pair" combination. Therefore, the additional communication channels may be termed "pair-to-pair" channels. GB2468925 discloses that a signal which propagates along a twisted pair cable between two of the twisted pairs can propagate reliably and over useful distances, without significantly altering the transmission of signals within the individual twisted pairs. Consequently, the "pair-to-pair" signal can propagate in addition to the differential voltage signals which typically propagate within each twisted pair when the twisted pair cable is in use. Therefore the test signals can be introduced into the "pair-to-pair" channel and these the "pair-to-pair" signals can be used to monitor the operation of the network without disrupting the normal operation of the network.

UK patent application GB1009184.1, also by the present inventors, and the content of which is herewith incorporated in its entirety, discloses signal processing apparatuses and methods for use with a plurality of cable lines, e.g. cable lines including one or more twisted pair cables. In particular, GB1009184.1 relates to apparatuses and methods for analysing one or more characteristics of a test signal coupled out from one of a plurality of cable lines. GB1009184.1 patent application presents apparatuses and methods for analysing a characteristic of a test signal, e.g. a "pair-to-pair" signal, coupled out by a coupling unit, to determine whether that test signal has propagated directly to the coupling unit via a single cable line or has propagated indirectly to the coupling unit via crosstalk between different cable lines. A copy of UK patent application number GB1009184.1 is annexed to this patent application.

The present invention has been devised in light of the above considerations.

In general, the present invention relates to developments concerning an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line; and

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line;

wherein the apparatus includes an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network and/or a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units.

As described below in further detail, such an apparatus may use non-contact coupling units as disclosed in GB2468925 and/or a signal processing unit as disclosed in UK patent application GB1009184.1, a copy of which is annexed hereto. The apparatus may operate in parallel with the network. The following disclosure relates to, amongst other things, an example of the hardware functionality required to realise such an apparatus; an installation sequence for the apparatus such that the apparatus can be easily fitted onto the network; and the functionality underpinning the apparatus, which may be implemented in software.

For the avoidance of any doubt, if the apparatus is for both identifying interconnections in a network comprising a plurality of cable lines and for determining the physical state of cable lines in the network, the interconnection identification means may use the same hardware as the state determining means.

In a first aspect, the invention may provide an apparatus for identifying interconnections in a network comprising a plurality of cable lines, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line; and

an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network;

wherein the interconnection identification means is configured to, if any one of the transmitter coupling units is coupled to the same cable line as a selected one of the receiver coupling units, identify the interconnection between the transmitter coupling unit and the selected receiver coupling unit by:

(i) selecting a subset of the transmitter coupling units;

(ii) conveying, at least once, the same test signal to each of the transmitter coupling units in the selected subset at substantially the same time so that, for each of the transmitter coupling units in the selected subset that is coupled to a respective cable line, the transmitter coupling unit couples the test signal into the respective cable line;

(iii) determining whether the selected subset of transmitter coupling units includes a transmitter coupling unit that is coupled to the same cable line as the selected receiver coupling unit based on whether the selected receiver unit couples out, from the cable line to which it is coupled, a test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset; and

(iv) selecting a new subset of the transmitter coupling units based on the determination in step (iii), and performing steps (ii) and (iii) for the newly selected transmitter coupling units; and

(v) if necessary, repeating step (iv) until the interconnection between the transmitter coupling unit and the selected receiver coupling unit is identified.

Identifying an interconnection in this way has been found to be much more efficient in quickly identifying an interconnection between transmitter and receiver coupling units than other methodologies, e.g. in which a test signal is coupled to the transmitter coupling units one at a time.

In this context, a signal which has propagated directly from one coupling unit to another is a signal which propagates along a cable line to which both coupling units are coupled, i.e. in contrast to a signal which propagates indirectly from one coupling unit to another e.g. via one or more coupling paths between different cable lines to which the coupling units are respectively coupled.

For the avoidance of doubt, the same test signal may be conveyed to each of the transmitter coupling units in a selected subset at substantially the same time in many different ways, e.g. by generating a test signal in a single signal generating unit and splitting the test signal so it can be conveyed to more than one transmitter coupling unit e.g. using one or more splitter unit as described below, and/or by generating the same test signal independently using a plurality of signal generating units so that the same test signal can be conveyed to more than one transmitter coupling unit e.g. using one or more splitter unit as described below.

Preferably, the interconnection identification means is also configured to identify the absence of an interconnection between the selected receiver coupling unit and any of the transmitter coupling units. Thus, the interconnection identification means may be configured to identify either an interconnection between one of the transmitter coupling units and the selected receiver coupling unit or the absence of such an interconnection, depending on which of these conditions is true.

Accordingly, the interconnection identification means may be configured to identify either an interconnection between one of the transmitter coupling units and the selected receiver coupling unit or the absence of such an interconnection by:

(i) selecting a subset of the transmitter coupling units;

(ii) conveying, at least once, the same test signal to each of the transmitter coupling units in the selected subset at substantially the same time so that, for each of the transmitter coupling units in the selected subset that is coupled to a respective cable line, the transmitter coupling unit couples the test signal into the respective cable line;

(iii) determining whether the selected subset of transmitter coupling units includes a transmitter coupling unit that is coupled to the same cable line as the selected receiver coupling unit based on whether the selected receiver unit couples out, from the cable line to which it is coupled, a test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset; and

(iv) selecting a new subset of the transmitter coupling units based on the determination in step (iii), and performing steps (ii) and (iii) for the newly selected transmitter coupling units; and

(v) if necessary, repeating step (iv) until an interconnection between one of the transmitter coupling units and the selected receiver coupling unit or the absence of such an interconnection is identified.

The selecting of a new subset of the transmitter coupling unit in step (iv) based on the determination in step (iii) may be made according to a large number of possible search algorithms.

For example, the interconnection identification means may be further configured so that, if it is determined in step (iii) that the selected subset of transmitter coupling units includes a transmitter coupling unit that is coupled to the same cable line as the selected receiver coupling unit, then step (iv) includes:

(a) disregarding any transmitter coupling units that are not selected for the selecting of any new subsets of the transmitter coupling units; and

(b) selecting a subset of the previously selected transmitter coupling units as the new subset of the transmitter coupling units.

Preferably, step (b) includes selecting a subset which contains half or approximately/substantially half of the previously selected transmitter coupling units as the new subset of the transmitter coupling units. This has been found to be found a particularly efficient way to identify an interconnection, and may form part of a binary tree search algorithm, e.g. as described below.

Preferably, the interconnection identification means is further configured so that, if it is determined in step (iii) that the selected subset of transmitter coupling units does not include a transmitter coupling unit that is coupled to the same cable line as the selected receiver coupling unit, then step (iv) includes:

(a) disregarding any transmitter coupling units that are selected for the selecting of any new subsets of the transmitter coupling units; and

(b) selecting all or a subset of the not selected and not disregarded transmitter coupling units as the new subset of the transmitter coupling units.

Preferably, step (b) includes selecting a subset which contains half or approximately/substantially half of the not selected and not (previously) disregarded transmitter coupling units. This has been found to be found a particularly efficient way to identify an interconnection, and may form part of a binary tree search algorithm, e.g. as described below.

The selecting of a new subset of the transmitter coupling unit in step (iv) based on the determination in step (iii) may be made according to a binary tree search algorithm. The binary tree search algorithm may involve, for example, initially selecting a subset preferably containing half or approximately/substantially half of the selected transmitter coupling units in step (i). If, in step (iii) it is determined that the selected subset does not include a transmitter coupling unit that is coupled to the same cable line as the selected receiver unit, then a subset containing the remaining transmitter units is selected as a new subset in step (iv). If, it is then determined that this subsequently selected subset does not include a transmitter coupling unit, then the absence of an interconnection between the selected receiver coupling unit and any of the transmitter coupling units can be identified. However, if it determined for either selected subset that the selected subset includes a transmitter coupling unit that is coupled to the same cable line as the selected receiver unit, then a subset preferably containing half or approximately/substantially half of the previously selected transmitter coupling units is then selected as a new subset. This can be repeated until the interconnection between one of the transmitter coupling units and the selected receiver coupling unit is identified.

In some embodiments, the determination in step (iii) of whether the selected receiver unit couples out, from the cable line to which it is coupled, a test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset, may be a trivial task if there is little or no crosstalk between cable lines in the network.

However, the presence of crosstalk between cable lines in the network may make it more difficult to determine whether the selected receiver unit couples out, from the cable line to which it is coupled, a test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset. Crosstalk has been found to create particular difficulties for determining whether a signal which has propagated between at least two conductors in a cable, e.g. a signal which has propagated between two twisted pairs in a cable, has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset or has propagated indirectly, e.g. via one or more coupling paths between different cable lines. However, such difficulties can be overcome using the techniques described in UK patent application number 1009184.1, a copy of which is annexed hereto. In particular, this UK patent application describes how to determine whether a signal which has propagated between at least two conductors in a cable line has propagated directly from a transmitter ("first") coupling unit to a receiver ("second") coupling unit, by analysing one or more characteristics of the signal coupled out from a cable line by the receiver coupling unit.

Accordingly, the interconnection identification means may include a signal processing unit configured to, if any of the receiver coupling units couples out a test signal, analyse one or more characteristics of the test signal to determine, based on the one or more analysed characteristics, whether the test signal has propagated directly to the receiver coupling unit from one of the transmitter coupling units. The signal processing unit may be configured to analyse one or more characteristics of the test signal to determine, based on the one or more analysed characteristics, which of the following conditions is true: (i) the test signal is a direct signal which has propagated directly from a transmitter coupling unit to the receiver coupling unit via a single cable line to which the first and second coupling unit are coupled; (ii) the test signal is a crosstalk signal that has propagated indirectly from a transmitter coupling unit to the receiver coupling unit via one or more coupling paths between different cable lines to which the transmitter and receiver coupling units are respectively coupled.

Thus, in step (iii), the signal processing unit may be used to determine whether the selected receiver unit couples out, from the cable line to which it is coupled, a test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset. The signal processing unit may be form part of a signal analysing unit included in the interconnection identification means.

The interconnection identification means may be configured so that step (ii) includes conveying, more than once, the same test signal to each of the transmitter coupling units in the selected subset at substantially the same time. Conveying the same test signal to each of the transmitter coupling units in the selected subset twice or more than twice may be useful, for example, in embodiments in which each transmitter coupling unit includes two pairs of electrodes for coupling a voltage signal into a respective cable line by non-contact coupling with twisted pairs in the cable line so that the voltage signal propagates between two or more of the twisted pairs. Having two separate pairs of electrodes for coupling a voltage signal into a twisted pair cable was disclosed, for example, in GB2468925, US2011/0181374 and WO2010/109211, and it is useful to avoid the problem of one of the pairs of electrodes in a transmitter coupling unit being in a "null" location such that the signal it couples into a twisted pair cable is not received by a receiver coupling unit. Accordingly, step (ii) may in some embodiments include conveying the same signal to a first pair of electrodes in each of the transmitter coupling units in the selected subset at a substantially the same first time and then, subsequently, conveying the same signal to a second pair of electrodes in each of the transmitter coupling units in the selected subset at a substantially the same second time.

The apparatus may additionally be for determining the physical state of cable lines in the network and may therefore include a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units as described above.

The first aspect of the invention may provide a method including method steps corresponding to the use of an above described apparatus.

The interconnection identification means may include:

at least one signal generating unit configured to generate the test signal; and

conveying means configured to convey the test signal generated by the at least one signal generating unit to the plurality of transmitter coupling units.

The conveying means may include at least one splitter unit configured to receive the test signal via a single input signal path from the signal generating unit and to output the test signal via a plurality of output signal paths. Thus, the splitter unit provides a simple means to allow the conveyance of the same test signal to a plurality of the transmitter coupling units at the same time.

Each output signal path of the at least one splitter unit may include a respective switch operable to control whether a test signal is outputted via the output signal path and/or a balun. The switches may provide a convenient means for conveying the test signal only to a subset of the transmitter coupling units. Each switch (in the at least one splitter unit) may be a switchable amplifier. This helps to reduce the creation of reflections in the output signal path.

The conveying means may include at least one further splitter unit configured to receive the test signal via a single input signal path from the output signal path of a splitter unit and to output the test signal via a plurality of output signal paths (e.g. directly to electrodes of a transmitter coupling unit). Splitting an already split test signal in this way provides a simple means to allow the conveyance of the same test signal to a plurality of the transmitter coupling units at the same time.

Each output signal path of the at least one further splitter unit may include a respective switch operable to control whether a test signal is outputted via the output signal path and/or a balun. The switches may provide a convenient means for conveying the test signal only to a subset of the transmitter coupling units. To reduce cost, each switch (in the at least one further splitter unit) may be an analogue switch, preferably an analogue switch having a high "off" isolation. Reducing reflections in the at least one further splitter unit may not be as important as reducing reflections in the at least one splitter unit.

One or more (preferably all) of the splitter units and/or further splitter units may include a test signal detector for detecting a test signal from the at least one signal generating unit. The or each test signal detector may be a radio frequency detector. The or each radio frequency detector may comprise an arrangement including a diode, a resistor and a capacitor.

The interconnection identification means may be configured to identify interconnections between the signal generating unit, the splitter units and/or the further splitter units by generating test signals using the signal generating unit and detecting the test signals using one or more of the test signal detectors.

The conveying means may include switching means operable to control which of the plurality of transmitter coupling units receives the test signal from the signal generating unit. The switching means may therefore include: a respective switch located in each output signal path of at least one splitter unit; and/or a respective switch located in each output signal path of at least one further splitter units, as described above.

The interconnection identification means may include:

a signal analysing unit for analysing a test signal coupled out from a cable line by one of the plurality of receiver coupling units; and

conveying means configured to convey a test signal coupled out from a cable line by one of the plurality of receiver coupling units to the signal analysing unit.

The conveying means may include switching means operable to couple any one of the plurality of receiver coupling units to the signal analysing unit via a signal path which is common to all receiver coupling units.

The switching means may include a respective switch located between each receiver coupling unit and the common signal path.

In a second aspect, the invention may provide an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line;

wherein the apparatus includes an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network and/or a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units;

wherein the interconnection identification means and/or state determining means includes:

at least one signal generating unit configured to generate the test signal; and

conveying means configured to convey the test signal generated by the at least one signal generating unit to the plurality of transmitter coupling units;

wherein the conveying means includes at least one splitter unit configured to receive the test signal via a single input signal path from the signal generating unit and to output the test signal via a plurality of output signal paths.

The apparatus may have any feature described in connection with the first aspect of the invention, e.g. at least one further splitter unit, e.g. switching means. Thus, the second aspect of the invention may provide an apparatus including such features, but without necessarily including an interconnection identification means as set out in the first aspect of the invention.

In a third aspect, the invention may provide an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line;

wherein the apparatus includes an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network and/or a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units;

wherein the interconnection identification means and/or state determining means includes:

at least one signal generating unit configured to generate the test signal; and

conveying means configured to convey the test signal generated by the at least one signal generating unit to the plurality of transmitter coupling units;

wherein the conveying means includes:

at least one splitter unit configured to receive the test signal via a single input signal path from the signal generating unit and to output the test signal via a plurality of output signal paths;

optionally, at least one further splitter unit configured to receive the test signal via a single input signal path from the output signal path of a splitter unit and to output the test signal via a plurality of output signal paths;

wherein one or more (preferably all) of the splitter units and/or further splitter units includes a test signal detector for detecting a test signal from the at least one signal generating unit.

The apparatus may have any feature described in connection with the first aspect of the invention, e.g. the interconnection identification means and/or state determining means may be configured to identify interconnections between the signal generating unit, the splitter units and/or the further splitter units by generating test signals using the signal generating unit and detecting the test signals using one or more of the test signal detectors. Thus, the third aspect of the invention may provide an apparatus including such features, but without necessarily including an interconnection identification means as set out in the first aspect of the invention.

In a fourth aspect, the invention may provide an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line;

wherein the apparatus includes an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network and/or a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units;

wherein the interconnection identification means and/or state determining means includes:

a signal analysing unit for analysing a test signal coupled out from a cable line by one of the plurality of receiver coupling units; and

conveying means configured to convey a test signal coupled out from a cable line by one of the plurality of receiver coupling units to the signal analysing unit;

wherein the conveying means includes switching means operable to couple any one of the plurality of receiver coupling units to the signal analysing unit via a signal path which is common to all receiver coupling units.

The apparatus may have any feature described in connection with the first aspect of the invention, e.g. the switching means may include a respective switch located between each receiver coupling unit and the common signal path. Thus, the fourth aspect of the invention may provide an apparatus including such features, but without necessarily including an interconnection identification means as set out in the first aspect of the invention.

In a fifth aspect, the invention may provide an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line;

wherein the apparatus includes an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network and/or a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units;

wherein the interconnection identification means and/or state determining means includes:

at least one signal generating unit configured to generate the test signal; and

a wander lead for coupling, via an additional transmitter coupling unit, the test signal generated by the at least one signal generating unit into any one of the cable lines in a network comprising a plurality of cable lines.

The wander lead may include or be coupled to the additional transmitter coupling unit.

In a sixth aspect, the invention may provide an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line;

wherein the apparatus includes an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network and/or a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units;

wherein the interconnection identification means and/or state determining means includes at least one signal generating and/or analysing unit configured to generate the test signal and/or analyse a test signal coupled out by one of the plurality of receiver coupling units;

wherein the at least one signal generating and/or analysing unit includes a synch block which allows the signal generating and/or analysing unit to be synchronised with other signal generating and/or analysing units.

Synchronising the signal generating and/or analysing unit is useful, for example, in using multiple signal generating units to generate the same test signal at substantially the same time, e.g. as may be useful in connection with the first aspect of the invention.

In a seventh aspect, the invention may provide an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line;

wherein the apparatus includes an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network and/or a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units;

wherein the interconnection identification means and/or state determining means includes at least one cable including a plurality of twisted pairs, wherein the interconnection identification means is configured such that:

a first twisted pair in the at least one cable carries a test signal generated by a signal generating unit; and/or

a second twisted pair in the cable carries a first communications signal for providing information from one component in the interconnection identification means and/or state determining means to another component in the interconnection identification means and/or state determining means; and/or

a third twisted pair in the cable carries a second communications signal for providing information from one component in the interconnection identification means and/or state determining means to another component in the interconnection identification means and/or state determining means, wherein the second communications signal propagates in a direction opposite to that of the first communications signal; and/or

a fourth twisted pair in the cable carriers power for powering one or more components of the interconnection identification means.

The interconnection identification means and/or state determining means may include a signal generating unit configured to generate the test signal.

The communication signal(s) may be transmitted, for example, according to the RS485 standard. The components between which communication signals may be transmitted may include, for example, a signal generating and/or analysing unit configured to generate the test signal and/or analyse a test signal coupled out by one of the plurality of receiver coupling units; a splitter unit; and/or a further splitter unit.

In an eighth aspect, the invention may provide an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective cable line in a network comprising a plurality of cable lines and to couple a test signal into the respective cable line;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to a respective cable line in the network and, if a test signal is present in the respective cable line, to couple the test signal out from the respective cable line;

wherein the apparatus includes an interconnection identification means configured to identify interconnections between the transmitter coupling units and the receiver coupling units by cable lines in the network and/or a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units;

wherein the interconnection identification means and/or state determining means is configured to perform an installation sequence in which each transmitter coupling unit and each receiver coupling unit is associated with a respective port in the network.

The interconnection identification means may further be configured to record in a database the association of each transmitter coupling unit and each receiver coupling unit with a respective port in the network.

The installation sequence may, comprise, for example:

(i) supplying prompts to a user;

(ii) manual inputting of data by the user in response to the prompts.

In an ninth aspect, the invention may provide a coupling unit for coupling a voltage signal to and/or from a cable including a plurality of twisted pairs, the coupling unit having:

a first electrode and a second electrode arranged to produce an electric field therebetween to couple a voltage signal to the cable by non-contact coupling with the twisted pairs so that the voltage signal propagates along the cable between at least two of the twisted pairs and/or arranged to receive a voltage signal which has propagated along the cable between at least two of the twisted pairs by non-contact coupling with at least two of the twisted pairs between which the voltage signal has propagated;

wherein the first and/or second electrodes of the coupling unit are located (preferably printed) on a flexible circuit board.

The flexible circuit board provides a convenient means of providing electrodes which can easily be pressed against the sleeve of a twisted pair cable.

The first and second electrodes may be located (preferably printed) on one side of the flexible circuit board. A ground plane may be located (preferably printed) on an opposite side of the flexible circuit board to the first and second electrodes. This arrangement helps provide shielding for the first and second electrodes.

The flexible circuit board may have a comb (e.g. ctenoid) shape, with a plurality of projections forming the comb shape.

The first and second electrodes of the coupling unit are preferably located (preferably at a distal end) on a projection of the comb shape.

The coupling unit may have a third electrode and a fourth electrode arranged to produce an electric field therebetween to couple a voltage signal to the cable by non-contact coupling with the twisted pairs so that the voltage signal propagates along the cable between at least two of the twisted pairs and/or arranged to receive a voltage signal which has propagated along the cable between at least two of the twisted pairs by non-contact coupling with at least two of the twisted pairs between which the voltage signal has propagated. In this case, the third and fourth electrodes may be located on a projection of the comb shape that is different to that on which the first and second electrodes of the coupling unit are mounted.

The pairs of electrodes from other coupling units may also be located on other projections of the comb shape.

The coupling unit may include a clip made of resilient/elastic material (e.g. plastic), the clip being configured to press the first and second electrodes (and optionally the third and fourth electrodes) of the coupling unit against the sleeve of a twisted pair cable.

The flexible circuit board may include conductive pads for connecting the first and second electrodes (and optionally the third and fourth electrodes) to corresponding pads on an external circuit board.

The flexible circuit board may be configured to be connected to the external circuit board by clamping the conductive pads of the flexible circuit board against the corresponding pads of the external circuit board.

The coupling unit may be for use with any apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network, e.g. as described herein.

Any interconnection identification means and/or state determining means described herein may include at least one signal generating unit configured to generate the test signal and/or at least one signal analysing unit configured to analyse a test signal coupled out by one of the plurality of receiver coupling units. A signal generating unit and an analysing unit may be provided by a single unit, which unit may be referred to e.g. as a “scanner”.

In any apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network described herein, each transmitter coupling unit may be configured to couple a test signal into a respective cable line in the network such that the test signal propagates along the respective cable line between at least two conductors in the respective cable line. The at least two conductors in the respective cable line may be twisted pairs in the cable line. Thus, each transmitter coupling unit may be configured to couple a test signal into a respective cable line in the network such that the test signal propagates along the respective cable line between at least two twisted pairs in the respective cable line.

Equally, in any apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network described herein, each receiver coupling unit may be configured to couple a test signal out from a respective cable line in the network after it has propagated between at least two conductors in the respective cable line. The at least two conductors in the respective cable line may be twisted pairs in the cable line. Thus, each receiver coupling unit may be configured to couple a test signal out from a respective cable line in the network after it has propagated between at least two twisted pairs in the respective cable line.

In any apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network described herein, each transmitter coupling unit may be configured to couple a test signal into a respective cable line in the network by non-contact coupling with conductors in the respective cable line. Equally, each receiver coupling unit may be configured to couple a test signal out from a respective cable line in the network by non-contact coupling with the conductors in the respective cable line. In this context, non-contact coupling refers to coupling that does not involve direct electrical (i.e. ohmic) contact with the conductors of the cable line.

Coupling units capable of coupling a test signal into (or out from) a twisted pair cable line so that the signal propagates (or after the signal has propagated) between at least two twisted pairs in the twisted pair cable line by non-contact coupling are disclosed, for example, in UK patent application number GB2468925, US2011/0181374 and WO2010/109211, and also in UK patent application number GB1009184.1, a copy of which is annexed hereto.

Accordingly, in any apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network described herein, each transmitter coupling unit may include any one or more of the following features: first and second electrodes arranged to produce an electric field therebetween to couple a voltage signal (which may, for example, be a test signal generated by a signal generating unit) into a twisted pair cable by non-contact coupling with twisted pairs in the twisted pair cable so that the voltage signal propagates along the twisted pair cable between at least two of the twisted pairs; electrical isolation means (e.g. a balun) arranged to electrically isolate the electrodes from the signal generating unit; shielding for shielding the electrodes from an external electromagnetic field; means for converting (e.g. a choke) a single-ended voltage signal from a signal generating unit into a differential voltage signal to be coupled to the electrodes; and a housing which may be arranged to be clipped onto a twisted pair cable.

Likewise, in any apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network described herein, the or each receiver coupling unit may include any one or more of the following features: first and second electrodes arranged to couple a voltage signal (which may, for example, be a test signal that was coupled into one of the plurality of cable lines by a transmitter coupling unit) out from a twisted pair cable by non-contact coupling with at least two of the twisted pairs in the twisted pair cable between which the voltage signal has propagated; electrical isolation means (e.g. a balun) arranged to electrically isolate the electrodes from the signal processing unit; shielding for shielding the electrodes from an external electromagnetic field; means for converting (e.g. a choke) a differential voltage signal from the electrodes into a single-ended voltage signal to be coupled to a signal processing unit; a housing which may be arranged to be clipped onto a twisted pair cable.

Any test signal described herein may be a signal having characteristics such that, when it is coupled out from a cable line by a receiver coupling unit, the characteristics of the test signal can be analysed to determine whether the resulting second test signal has propagated directly to the receiver coupling unit from a transmitter coupling units. The present inventors have found that signals suitable for performing time domain reflectometry or frequency domain reflectometry are suitable for such purposes. Accordingly, a test signal described herein may be a test signal suitable for performing time domain reflectometry and/or a first test signal suitable for performing frequency domain reflectometry, which may be a voltage signal.

In time domain reflectometry, a system response is measured as a function of time. A test signal suitable for time domain reflectometry might be, for example, an impulse or narrow transient test signal, e.g. having a duration of less than 10 ns (which corresponds to an electrical length of 2 meters).

In frequency domain reflectometry, a system response is measured as a function of frequency. A test signal suitable for frequency domain reflectometry might be, for example, a frequency swept sine wave or pseudo random noise. Frequency domain information can be converted into a corresponding time domain response via an inverse Fourier transform, as would be known to those skilled in the art.

In any apparatus for determining the physical state of cable lines in a network described herein, a state determining means may be configured to determine the physical state of a cable line in the network e.g. by coupling a test signal into a selected cable line using one of the transmitter coupling units, coupling a test signal out of the selected cable line using one of the receiver coupling units and analysing, e.g. in a signal analysing unit, the test signal coupled out of the selected cable line by the receiver coupling unit so as to determine a physical state of the cable. For example, the physical state of the cable line may be determined by comparing a received test signal with a reference test signal, as is known in the art of reflectometry. An apparatus for determining the physical state of cable lines in a network is shown, for example, in FIG. **3**.

Herein, the term "cable" preferably refers to any cable capable of carrying a signal, e.g. a voltage signal or an optical signal. The term "cable line" preferably refers to either a cable or a plurality of cables connected together so as to be capable of carrying a signal. In some embodiments, the term "cable" may refer to a cable including at least two conductors. In some embodiments, the term "cable line" may refer to either one such cable or to a plurality of such cables whose conductors have been directly, i.e. by direct electrical ("ohmic") contact, coupled together.

Herein, when it is described herein that a signal propagates "between" at least two conductors in a cable line, it is meant that the signal propagates along the cable line due to a coupling between the conductors, the signal being difference in state between the conductors. Such a signal is commonly referred to as "differential" signal. A differential signal is therefore distinguished from a so-called "common mode" signal, where all the conductors have substantially the same state and the signal is a difference in state between all the conductors and an external reference (e.g. ground).

For example, a signal that propagates between at least two conductors in a cable line may be a voltage signal, i.e. a difference in voltage between at least two conductors in the cable line, which propagates along the cable line due to inductive and capacitive coupling between at least two conductors. Here, the capacitance per meter and inductance per meter will generally determine e.g. the speed of propagation of such a voltage signal.

For the avoidance of doubt, when a signal is described herein as propagating along a cable line, the signal does not have to propagate along the entire length of the cable line. Likewise, when a signal is described herein as having propagated along a cable line, the signal does not have to have propagated along the entire length of the cable line.

In another aspect of the invention, there may be provided a kit of parts for forming an apparatus as set out in any above aspect, e.g. an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network. The kit of parts may include, for example, a plurality of transmitter coupling units, and/or a plurality of receiver coupling units, and/or an interconnection identification means, and/or a state determining means as set out above and/or subcomponents thereof.

In another aspect of the invention, there may be provided any component of an apparatus as set out in any above aspect, e.g. an apparatus for identifying interconnections in a network comprising a plurality of cable lines and/or for determining the physical state of cable lines in the network. The component may be, for example, a transmitter coupling unit, a receiver coupling unit, an interconnection identification means or a state determining means as set out above, or a subcomponent thereof.

In another aspect of the invention, there may be provided a method which may include any method step corresponding to the use of any apparatus or apparatus feature described in connection with any above aspect of the invention.

The invention also includes any combination of the aspects and preferred features described except where such a combination is clearly impermissible or expressly avoided.

Examples of our proposals are discussed below, with reference to the accompanying drawings in which:

FIG. **1** shows a typical patch system organised into a server row, a cross-connect row and a network row.

FIG. **2** is a block diagram of a system configured to determine interconnection status such as a map of the patch leads with a local area network.

FIG. **3** is a block diagram of a system configured to monitoring the physical status of the channels within the network. It will be apparent to one skilled in the art that an apparatus could be configured to have the functionality of the systems shown in both FIG. **2** and FIG. **3**. The two functions have been illustrated in separate drawings in this application for clarity.

FIG. **4** is a representation illustrating the main component blocks contained with the "Scanners" shown in FIGS. **2** and **3**.

FIG. **5** is a representation of the main circuit blocks contained in the "24 way splitter" shown in FIGS. **2** and **3**.

FIG. **6** is a representation the interconnection details between the "24 way splitter" and the "Tx front end units".

FIG. **7** is a representation of the main circuit blocks contained in the "Tx Front End units" shown in FIGS. **2** and **3**.

FIG. **8** is a representation of the main circuit blocks contained in the "Rx Front End units" shown in FIGS. **2** and **3**.

FIGS. **9**(*a*)-(*d*) are representations showing the use of flexible printed circuit for implementing the transmitter and/or receiver plates.

FIG. **10** is a representation showing how the transmitter and/or receiver plates can be clipped around the cable in a format that can be easily deployed in the field.

FIGS. **2** and **3** show block diagrams for the system hardware. The system preferably has two main modes of operation in which FIG. **2** shows the system operating in a "patching" mode, whereby the system determines a connectivity map of the patch cable, which the user has inserted in between the patch panels to configure the local area network. FIG. **3** shows the system operating in a "monitoring" mode whereby the system inspects each channel on the network e.g. by performing reflectometry to look for impedance changes in each channel. Any impedance changes may indicate a change in status of the channel such as a fault in the cable or a unit being unplugged at the end of the channel. The system is preferably controlled by a host PC, which is connected to one or more scanner units. In this example, Ethernet, which is labelled IP, is used to provide communications between each scanner unit and the host PC. The host PC preferably reports information about the network and receives instructions over the Internet, labelled as the Cloud. The system may be controlled by programmes which are either local on the host PC or hosted on external resources in the Cloud via external service providers.

Referring to FIG. **2**, the system preferably determines a connectivity map by applying a test signal to one or more transmitter coupling units, which are labelled "Tx plates", and then monitors the signal from one or more receiver coupling units, labelled "Rx plates". The transmitter coupling units and the receiver coupling units may typically be placed directly behind the patch panels. An adequate number coupling units is preferably used such that a full connectivity map between all relevant ports can be determined by the system. Any test signal received by the Rx plates is preferably analysed by signal processing algorithms, such as those described in GB1009184.1, to determine if the signal has been conveyed directly between the transmitter coupling unit and the receiver coupling unit, in which case there is a patch lead present, or via an unwanted route, such as alien crosstalk between UTP cables in the network. The system preferably implements a search algorithm to determine all the directly conveyed signal paths between every transmitter coupling unit and every receiver coupling unit. Each directly conveyed signal path is evidence of a patch lead connected between the respective ports. The search algorithm preferably ensures that all possible patch lead positions are examined in an efficient manner. One possible search algorithm is a binary tree in which half the possible interconnections from the ports with transmitter coupling units a port with a receiver coupling unit are tested first; if the result shows no direct connection then the other half of the possible interconnections are tested; if the result shows no direct connection then no patch lead is present; alternatively if a direct connection is detected on either half, then the algorithm tests one quarter of the remaining possible interconnections; then one eight etc until the presence of a interconnection or not has been established. It should be noted that there are many variations on this theme and although a binary tree search is thought to be the most efficient, any structured and logical search may in practice be performed by the system to ensure that all possible direct connections are determined.

In order to apply the test signal to one or more transmitter coupling units, the system preferably contains as series of splitters and Tx front end coupling couplings, which contain switches or switched amplifiers as appropriate to convey the test signal to one or any combination of transmitter coupling units as required. The internal operation of the splitter and Tx front end units are shown in FIGS. **5** and **7** respectively. In addition, the scanner may provide an output for a wander lead, which might simply be a transmitter coupling unit on a free lead. The wander lead may be hand held or attached to any accessible cable in the network as required by the user to test the connectivity of a particular port or cable.

The structure of UTP is such that the individual twisted pairs are held together by a sleeve. Within the sleeve, the bundle of twisted pairs is also twisted by the manufacturers with an overall twist rate, with a value denoted here as lambda. It is highly preferable to ensure that both the transmitter coupling units and receiver coupling units are positioned next to the same corresponding pairs inside the sleeve of the UTP cable. Unfortunately, the sleeve is usually not transparent and consequently the correct position of the coupling units cannot easily be determined. To overcome this problem two transmitter coupling units are preferably deployed on each cable as shown. The two transmitter coupling units are preferably aligned in the same radial direction, but preferably spaced by lambda/4, which helps to ensure that one of the two coupling units will have good coupling to the corresponding pairs under the appropriate receiver coupling unit.

The signal received by any receiver coupling unit can be conveyed back to a scanner by a switching network contained in the Rx front end units and a radio frequency bus, such as a coaxial cable, labelled Rx coax. The internal operation of an Rx front end unit and its connection to the Rx coax is shown in FIG. **8**.

The scanner units typically have the provision to service several splitter units and several Rx coax buses with multiple inputs and outputs of these types. This helps to ensure that a moderately sized network, such as one containing 500 ports can have the patch lead connectivity map determined with a single controller unit. For larger networks, multiple controller units may be needed in which case the timing of the signal capture and processing operation must be synchronised. Synchronisation can be achieved using dedicated connections between the scanner units. Typically one scanner unit will be programmed or configured to serve as the master and provide the necessary synchronisation signal to the other scanner units.

Communication between the scanner and the associated splitter and front end units is preferably achieved with a communication bus. A serial bus such as RS485 is a convenient means of implementing this communication as this can be connected in a daisy chain fashion around the respective units.

It should be noted that the architecture of FIG. **2** is preferably such that the delay that the transmitter test signal encounters from the scanner to the transmitter coupling units are approximately the same for all transmitter coupling units assuming that similar cable lengths are used for corresponding paths in the system. This helps to ensure that directly connected paths in the network are easy to identify by the signal processing algorithms later.

FIG. **3** shows the operation of the system when operating in the "monitoring" mode. Here only the relevant system block as shown. The monitoring functionality is preferably achieved using reflectometry. Reflectometry is an established technique which is well known by those skilled in the art of signal processing. Reflectometry can be implemented in a number of ways such as time domain reflectometry, frequency domain reflectometry and the like. The chosen method for this system is to perform reflectometry in the frequency domain, however other approaches are viable. Consequently, the scanner units preferably generate a test signal consisting of a wide band sweep of frequencies from 1 to 100 MHz, which typically contain 128 or 256 individual frequency values, which may be equally spaced. A similar test signal may also used for the "patching" mode described earlier.

The system preferably implements reflectometry by using a transmitter coupling unit to transmit the reflectometry signal and a receiver coupling unit to receive the reflectometry signal. The two coupling units are preferably positioned at integer multiples of lambda/2 to ensure adequate coupling to the same twisted pairs inside the sleeve of the UTP cable in a similar manner to that described earlier for "patching" mode. The system can be economically implemented using a transmitter coupling units and receiver coupling units in combinations to connect to their respective coupling units behind each patch panel. The association of pairs of transmitter and receiver front end units may be controlled using direct RS485 communications between them.

FIG. **4** shows a block diagram of the internal components inside a scanner unit. The scanners preferably contain a processor in this case a moderately powerful microcontroller, labelled μC, which communicates with the host PC via Ethernet and the splitter, Rx front end and Tx front end units using RS485. The microcontroller preferably contains the programmes necessary to control the units responsible for signal generation and signal acquisition. The circuit preferably used to synchronise scanner units is also shown. The synchronisation circuits help to ensure that the multiple scanner units can operate at the same clock frequency and that time critical signal acquisition and signal process function occur simultaneously. For example the synchronisation helps to ensure phase coherence during the capture and demodulation of the frequency sweeps. The signal processing functions such as digital demodulation is preferably performed by the field programmable gate array (FPGA). The FPGA controllers the signal generator, which is preferably a direct digital synthesiser (DDS), and which preferably generates the frequency sweep test signals described earlier. The DDS also preferably generates the reference frequency ($f-f_{IF}$) for the multiplier. The reference frequency is preferably offset by a fixed value to representing the intermediate frequency in the heterodyne demodulation scheme. The output from the DDS is also preferably conveyed to one or more outputs for the splitter and Tx front end units described earlier. Switchable amplifiers with enable lines (EN) are preferably used to select to activate the appropriate transmitter output on the scanner unit in order to convey the transmitter signal to the rest of the system as required. Twisted pair is preferably used as a convenient and low cost transmission medium for the transmitter signals. Baluns may also be added to help reduce the common mode signal applied the twisted pairs, which helps to minimise crosstalk in the system.

The signal capture scheme may consist of a relatively standard heterodyne demodulation method. The signal input is preferably conveyed to an analogue demodulator which contains a multiplier and a low pass filter as is common practice for such demodulators. The offset in frequency between the input signal and reference preferably results in a signal at the input to the analogue to digital converter (ADC) with a frequency of f_{IF}. The ADC signal preferably digitises this signal and the FPGA preferably implements a digital demodulation algorithm to determine the in-phase and quadrature values of the signal at each value of frequency contained in the frequency sweep. The scanner preferably uses a multiplier arrangement to select one of several possible receiver signals. The receiver signals are preferably relatively small and preferably require amplification and should be conveyed to the scanner using a good quality transmission medium such as coaxial cable.

FIG. **5** shows the internal circuitry of the splitter unit, which may contain 24 outputs. All signal lines are preferably differential. The input signal, RF In is preferably passed first passed through a balun to reject common mode signal components and then a buffer preferably helps to ensure that the input signal line is correctly matched to the input impedance of the splitter unit. Similarly output baluns and buffers amplifiers are preferably used to help minimise common mode interference in the system and match to the output lines, RF Out **1**, RF Out **2**, RF Out **3**, etc. respectively. The output buffers are preferably of a switchable type such that their outputs can be switched on or off by the corresponding enable line, EN**1**, EN**2**, EN**3** etc. A low power microcontroller such as a PIC type with an RS485 interface can be used to activate the appropriated RF Out lines as required by commands send along the RS485 bus. The splitter preferably also contains components for DC power management and LEDs for indication of functionality to the user, but these miscellaneous and ancillary components are not shown, which is the case for the main sub-units described in this document.

FIG. **6** contains an illustration of the routing of the lines for the RF transmitter signals, the RS485 communications serial communications bus, and the two DC power levels between the splitter unit and the Tx front end units. In this particular system, UTP and RJ45 connectors have been used as a convenient and economical means of conveying these lines. As shown, one UTP cable containing 4 twisted pairs can convey the RS485, signal and power lines, with the RS485 connected following a daisy chain path out and back between the splitter unit and the Tx front end units. This connection scheme preferably requires that the RJ45 connectors (Tx FE**1**, Tx FE**2**, etc in FIG. **2**) are populated in a strict sequence to ensure continuity of the RS485 line through all the transmitter front end units. In addition a 100 ohm termination is preferably be inserted in the first free Tx FE socket to help ensure that the RS485 bus is correctly terminated, thereby avoiding unwanted reflections and corrupted data.

FIG. **7** depicts the operation of a transmitter front end unit. This is similar in nature to the splitter unit shown in FIG. **5** and previously described earlier. For the purposes of brevity only the essential differences will be described. First analogue switches are preferably used at the output as a lower cost and lower power alternative to switchable amplifiers. The outputs of the transmitter front end unit are preferably fed directly via short leads, typically 10 cm to the plates in the transmitter coupling units. Consequently such short leads do not need driving with buffer amplifiers. Second, the transmitter front end unit is preferably made in section of 12 channels for convenience as many patch panels are 24 ports wide. The multiple of 12 allows the signal to be fed into the middle of the Tx FE signal to feed into a connector positioned in the middle of the unit. Third the transmitter front end unit preferably contains 48 output channels this is to accommodate to coupling units per cable on a 24 port patch panel. Four, a simple RF detect signal, typically consisting of a diode, resistor and capacitor is preferably used to detect when a transmitter signal has been applied to the RF In input. This is used later in the installation sequence to detect which transmitter front end units are connected to which outputs on the splitter and determine coincidence between their corresponding individual addresses stored on the programmes on each of the PIC microcontrollers.

FIG. **8** shows the architecture of a receiver front end unit. There are structural similarities between the converse functions on the transmitter side described for the splitter unit in FIG. **5** and the transmitter front end unit in FIG. **7**. Therefore for brevity only the key functional differences will be described here. First, of course the signal flow is in the opposite direction. Baluns are an useful feature on the input to help to ensure that the common mode signal is rejected and mainly the desired component, such as the pair to pair component is conveyed to the following stages. Second, amplifiers are useful at the input to both amplify the signal and present the required input impedance to the receiver coupling unit. The amplifiers preferably have switchable outputs such that the required receiver coupling unit signal is conveyed to the output. Clearly only one or no input amplifiers are enabled at a time. At the output, the signal is preferably routed through a pair of switch switches which serve a changeover function. This is typically a good quality switch such as a screen RF reed relay to preserve the integrity of transmission for signals on the Rx coax bus. The changeover switch preferably either connects the signal from this receiver front end unit to the Rx coax bus or passes the bus through to the next receiver front end unit in the chain.

FIGS. **9**(*a*)-(*d*) shows the construction of the coupling units. In particular, FIG. **9**(*a*) highlights the use of flexible printed board (PCB) material such as polyimide as a convenient and inexpensive means of realising the pair of plates required in either the transmitter coupling unit or the receiver coupling unit. FIG. **9**(*b*) show the view from the plate (i.e. electrode) side and FIG. **9**(*c*) is an illustration of the view from the ground plane side. The ground plane serves an useful electromagnetic screening role. FIG. **9**(*d*) shows how the individual elements for each coupling unit can be combined to form limbs of a comb shape (ctenoid) structure for ease of connection to a rigid PCB. To avoid a further soldering operation the metal conducting pads on the flexible PCB can be pressed directly against corresponding aligned and positioned conducting pads on the rigid PCB containing the circuitry for the receiver front end unit.

FIG. **10** illustrates the design in schematic view of a compliant elastic clip which may be used to press the plates on the flexible PCB against the sleeve of the UTP cable. An end view of the clip is provided here with the flexible PCB and the UTP cable in the middle.

When used in this specification and claims, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or integers.

The features disclosed in the foregoing description, or in the following claims, or in the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for obtaining the disclosed results, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure, without departing from the broad concepts disclosed. It is therefore intended that the scope of the patent granted hereon be limited only by the appended claims, as interpreted with reference to the description and drawings, and not by limitation of the embodiments described herein.

ANNEX

Copy of UK Patent Application GB1009184.1

In this copy of UK patent application GB1009184.1, the figures have been renumbered to avoid conflict with the other figures in this patent application, and the claims have been relabelled as "statements" to avoid confusion with the claims of this patent application.

Signal Processing Apparatuses and Methods

This invention relates to signal processing apparatuses and methods for use with a plurality of cable lines, e.g. cable lines including one or more twisted pair cables. In particular, this invention relates to apparatuses and methods for analysing one or more characteristics of a test signal coupled out from one of a plurality of cable lines. In some examples, the invention relates to a network interconnection identification apparatus for identifying interconnections between ports in a network.

Cables which include a plurality of twisted pairs, referred to as "twisted pair cables" herein, are well known. Such cables are commonly used for telecommunications purposes, e.g. computer networking and telephone systems. In the field of telecommunications, twisted pair cables are usually provided without shielding, as unshielded twisted pair (UTP) cables. However, shielded twisted pair (STP) cables are also known.

In this context, a "twisted pair" is a pair of conductors, usually a forward conductor and a return conductor of a single circuit, which have been twisted together. The conductors are usually twisted together for the purposes of cancelling out electromagnetic interference from external sources and to minimise crosstalk between neighbouring twisted pairs within a cable comprising a plurality of twisted pairs. In this way, each twisted pair provides a reliable respective communication channel for a signal, usually a differential voltage signal, to be conveyed within the twisted pair. Common forms of unshielded twisted pair (UTP) cables are category 5 and category 6 UTP cables which include eight conductors twisted together in pairs to form four twisted pairs.

The design and construction of twisted pair cables is carefully controlled by manufacturers to reduce noise due to electromagnetic interference and to reduce crosstalk between the twisted pairs within the cables. To this end, each twisted pair in a twisted pair cable normally has a different twist rate (i.e. number of twists per unit length along the cable) from that of the other twisted pairs in the twisted pair cable. It is also usual for the twisted pairs to be twisted around each other within the cable. Fillets or spacers may be used to separate physically the twisted pairs.

Networks including ports interconnected by a plurality of cables, such as local area networks (LANs), are also well known. LANs are typically used to enable equipment such as computers, telephones, printers and the like to communicate with each other and with remote locations via an external service provider. LANs typically utilise twisted pair network cables, usually in the form of UTP cables.

The cables used in LANs are typically connected to dedicated service ports throughout one or more buildings. The cables from the dedicated service ports can extend through the walls, floor and/or ceilings of the building to a communications hub, typically a communications room containing a number of network cabinets. The cables from wall and floor sockets within the building and from an external service provider are also usually terminated within the communications room.

A "patch system" may be used to interconnect various ports of the LAN within the network cabinets. In a patch system, all cable lines in the LAN can be terminated within the network cabinets in an organized manner. The terminations of the cable lines in the network are provided by the structure of the network cabinets, which are typically organised in a rack system. The racks contain "patch panels", which themselves utilise sets of ports, typically RJ-45 type connector ports, at which the cable lines terminate.

Each of the ports in each patch panel is hard wired to one of the cable lines in the LAN. Accordingly, each cable line is terminated on a patch panel in an organized manner. In small patch systems, all cable lines in the LAN may terminate on the patch panels of the same rack. In larger patch systems, multiple racks are used, wherein different cable lines terminate on different racks.

Interconnections between the various ports in the LAN are typically made using "patch cables", which are usually UTP cables including four twisted pairs. Each end of a patch cable is terminated by a connector, such as an RJ-45 type connector for inserting into an RJ-45 type connector port. One end of each patch cable is connected to the port of a first cable line and the opposite end of the patch cable is connected to the port of a second cable line. By selectively connecting the various cable lines using the patch cables, a desired combination of network interconnections can be achieved.

FIG. **22** shows a typical patch system organised into a server row **92**, a cross-connect row **93** and a network row **94**, which include patch panels **96***a*, **96***b*, **96***c*, **96***d*. Patch cables **10***a*, **10***b*, **10***c*, **10***d* are used to interconnect two ports through the patch system.

In many businesses, employees of a company are assigned their own computer network access number so that the employee can interface with the company's IT infrastructure. When an employee changes office locations, it is not desirable to provide that employee with newly addressed port in the network. Rather, to preserve consistency in communications, it is preferred that the exchanges of the ports in the employee's old office be transferred to the telecommunications ports in the employee's new location. This type of move is relatively frequent. Similarly, when new employees arrive and existing employees depart, it is usually necessary for the patch cables in the network cabinet(s) to be rearranged so that each employee's exchanges can be received in the correct location.

As the location of employees change, the patch cables in a typical cabinet are often manually entered in a computer based log. This is burdensome. Further, technicians often neglect to update the log each and every time a change is made. Accordingly, the log is often less than 100% accurate and a technician has no way of reading where each of the patch cables begins and ends. Accordingly, each time a technician needs to change a patch cable, that technician manually traces that patch cable between an internal line and an external line. To perform a manual trace, the technician locates one end of a patch cable. The technician then manually follows the patch cable until he/she finds the opposite end of that patch cable. Once the two ends of the patch cable are located, the patch cable can be positively identified.

It takes a significant amount of time for a technician to manually trace a particular patch cable, especially in large patch systems. Furthermore, manual tracing is not completely accurate and a technician may accidently go from one patch cable to another during a manual trace. Such errors result in misconnected patch cables which must be later identified and corrected.

Attempts have been made in the prior art to provide an apparatus which can automatically trace the common ends of each patch cable within local area networks, thereby reducing the labour and inaccuracy of manual tracing procedures.

For example, U.S. Pat. No. 5,483,467 describes a patching panel scanner for automatically providing an indication of the connection pattern of the data ports within a LAN, so as to avoid the manual task of identifying and collecting cable connection information. In one embodiment, which is intended for use with shielded twisted pair cables, the scanner uses inductive couplers which are associated with the data ports. The inductive coupler is disclosed as being operative to impose a signal on the shielding of shielded network cables in order to provide an indication of the connection pattern produced by connection of the cables to a plurality of ports.

In another embodiment of U.S. Pat. No. 5,483,467, the scanner is coupled to each data port by "dry contact" with a dedicated conductor in a patch cable. This is difficult to implement in practice, because most network cables have to meet a particular pre-determined standard in the industry, such as the RJ-45 type standard, in which there is no free conductor which could be used for determining interconnectivity.

U.S. Pat. No. 6,222,908 discloses a patch cable identification and tracing system in which the connectors of each patch cable contain a unique identifier which can be identified by a sensor in the connector ports of a telecommunications closet. By reading the unique identifier on the connectors of each patch cable, the system can keep track of which patch chords are being added to and removed from the system. Although this system avoids the use of dedicated conductors in the patch cable, it is difficult to implement because it requires use of non-standard patch cables, i.e. patch cables with connectors containing unique identifiers.

International Patent Application Publication Number WO00/60475 discloses a system for monitoring connection patterns of data ports. This system uses a dedicated conductor which is attached to the external surface of a network cable in order to monitor the connection pattern of data ports. Although this allows the system to be used with standard network cables, it still requires the attaching of dedicated conductors to the external surfaces of network cables and adapter jackets which are placed over the standard network cable.

U.S. Pat. No. 6,285,293 discloses another system and method for addressing and tracing patch cables in a dedicated telecommunications system. The system includes a plurality of tracing interface modules that attach to patch panels in a telecommunications closet. On the patch panels, are located a plurality of connector ports that receive the terminated ends of patch cables. The tracing interface modules mount to the patch panels and have a sensor to each connector port which detects whenever a patch cable is connected to the connector port. A computer controller is connected to the sensors and monitors and logs all changes to the patch cable interconnections in an automated fashion. However, this system cannot be retrofitted to an existing network and relies on the operator to work in a particular order if the patch cable connections are to be accurately monitored.

International Patent Application Publication Number WO2005/109015, which relates to the field of cable state testing, discloses a method of determining the state of a cable comprising at least one electrical conductor and applying a generated test signal to at least one conductor of the cable by a non-electrical coupling transmitter. The reflected signal is then picked up and compared with expected state signal values for the cable, so that the state of the cable can be determined. The present inventors have found that signals coupled to a twisted pair cable by the methods described in WO2005/109015 have a tendency to leak out from the twisted pair cable, especially when other twisted pair cables are nearby.

UK patent application number GB0905361.2, U.S. patent application Ser. No. 11/597,575 and International patent application number PCT/GB2010/000594, also by the present inventors, and the content of which is herewith incorporated in its entirety, describe apparatuses and methods for coupling a signal to and from a twisted pair cable by non-contact coupling with twisted pairs in the twisted pair cable, such that the signal propagates along the cable between at least two of the twisted pairs. These methods and apparatuses related to a discovery by the present inventors that a twisted pair cable provides communication channels (referred to as "pair-to-pair channels") between the twisted pairs within the twisted pair cable, these communication channels being additional to the respective communication channel provided within each twisted pair in the cable. In other words, a signal propagating between the twisted pairs could be transmitted on a standard UTP cable (i.e. with no specially adapted UTP cable needed) without interfering with signals propagating within individual twisted pairs of the standard UTP cable.

"Crosstalk" is a common problem within the field of networks. "Crosstalk" may be viewed as undesired signal coupling from one signal channel to another. For networks including a plurality of twisted pair cables, crosstalk may occur between the twisted pairs within individual twisted pair cables, but most commonly occurs between twisted pairs in different twisted pair cables, particularly when the twisted pairs have a similar twist rate. In industry, crosstalk between different twisted pair cables is sometimes referred to as "alien" crosstalk and is illustrated by FIG. **11***b*, which is described in more detail below.

The presence of crosstalk between twisted pair cables can cause serious difficulties for the operation of a network as it can cause signals to be routed via undesired paths between ports in the network. To address these difficulties, cables (e.g. category 5 and category 6 UTP cables), connectors and associated components are normally manufactured to ensure that levels of crosstalk are maintained within prescribed standards. In addition, cables must often be installed and connected according to guidelines in order to ensure that the network performs to the prescribed standards.

The present invention has been devised in light of the above considerations.

The present invention relates to a discovery by the present inventors that the characteristics of a test signal coupled out from one of a plurality of cable lines by a coupling unit are different depending on whether that test signal has propagated directly to the coupling unit via a single cable line or has propagated indirectly to the coupling unit via one or more coupling paths between different cable lines. By analysing one or more characteristics of such a test signal, the present inventors have found that it is possible to determine whether the test signal has propagated directly to the coupling unit via a single cable line or has propagated indirectly to the coupling unit via one or more coupling paths between different cable lines.

Accordingly, in general, the invention provides apparatuses and methods for analysing at least one characteristic of a test signal coupled out from one of a plurality of cable lines by a coupling unit to determine whether that test signal has propagated directly to the coupling unit via a single cable line or has propagated indirectly to the coupling unit via one or more coupling paths between different cable lines.

The determination of whether the test signal has propagated directly to the coupling unit via a single cable line or has propagated indirectly to the coupling unit via one or more coupling paths between different cable lines, may advantageously be used for operational or diagnostic purposes, e.g. to identify interconnections between ports in a network.

Herein, for brevity, a test signal which has propagated directly between a first coupling unit and a second coupling unit via a single cable line is referred to as a "direct signal" and a signal which has propagated between the first coupling unit and second coupling unit via a coupling path extending between different cable lines is referred to as a "crosstalk signal". As explained in more detail below, the present inventors have found that a direct signal has different characteristics (e.g. in the time and frequency domains) from a crosstalk signal. This difference is illustrated, for example, by FIGS. **11***a* and **11***b*, which are described in more detail below.

In a first aspect, the present invention provides a signal processing apparatus as set out in statement A.

In other words, the signal processing apparatus is able to distinguish between a direct signal and a crosstalk signal. In this way, the signal processing apparatus is different from the apparatuses described in UK patent application number GB0905361.2, U.S. patent application Ser. No. 11/597,575 and International patent application number PCT/GB2010/000594, also by the present inventors, since the apparatuses described in these patent applications are not configured to distinguish between these different types of signal.

Here, it should be appreciated that a determination by the signal processing unit that condition (i) is true indicates that the first cable line is also the second cable line. Likewise, it should be appreciated that a determination by the signal processing unit that condition (ii) is true indicates that the first cable line is different from the second cable line.

Here, it should also be appreciated that the signal processing unit may not be able to determine which of conditions (i) and (ii) is true for each and every second test signal coupled out by the second coupling unit. This might be the case, for example, if the second test signal does not result from a first test signal coupled into a first cable line by the first coupling unit. This might also be the case, for example, if the signal processing unit needs to analyse the characteristics of a plurality of second test signals, before it has enough information to determine whether condition (i) or (ii) is true for any one or more of those second test signals.

Herein, the term "cable" refers to a single cable including at least two conductors. The term "cable line" refers to either one such cable or to a plurality of such cables whose conductors have been directly, i.e. by direct electrical (ohmic) contact, coupled together.

Herein, when it is described herein that a signal propagates "between" at least two conductors in a cable line, it is meant that the signal propagates along the cable line due to a coupling between the conductors, the signal being difference in state between the conductors. Such a signal is commonly referred to as "differential" signal. A differential signal is therefore distinguished from a so-called "common mode" signal, where all the conductors have substantially the same state and the signal is a difference in state between all the conductors and an external reference (e.g. ground).

For example, a signal that propagates between at least two conductors in a cable line may be a voltage signal, i.e. a difference in voltage between at least two conductors in the cable line, which propagates along the cable line due to inductive and capacitive coupling between at least two conductors. Here, the capacitance per meter and inductance per meter will generally determine e.g. the speed of propagation of such a voltage signal.

For the avoidance of doubt, when a signal is described herein as propagating along a cable line, the signal does not have to propagate along the entire length of the cable line. Likewise, when a signal is described herein as having propagated along a cable line, the signal does not have to have propagated along the entire length of the cable line.

The signal processing apparatus may include the plurality of cable lines. The signal processing apparatus may include a network that includes the plurality of cable lines. The network may include a plurality of ports, which may be interconnected by the plurality of cable lines.

Although the apparatus may have only one first coupling unit and only one second coupling unit, the apparatus preferably includes a plurality of first coupling units and/or a plurality of second coupling units.

Preferably, the apparatus has a plurality of first coupling units, each first coupling unit being configured to couple to a respective first one of the plurality of cable lines and to couple a respective first test signal generated by the signal generating unit into the respective first cable line such that the respective first test signal propagates along the respective first cable line between at least two conductors in the respective first cable line.

Where there is a plurality of first coupling units, the first coupling units are preferably configured to couple respective first test signals generated by the test signal generating unit one at a time. In this way, interference between test signals in the plurality of cable lines, e.g. due to crosstalk, can be avoided. Also, coupling in first test signals one at a time may help the signal processing unit to determine which first coupling unit coupled in a first test signal that resulted in one or more second test signals subsequently coupled out by a plurality of second coupling units. Determining which first coupling unit coupled in a first test signal that resulted in one or more second test signals may be useful, for example, in helping the signal processing unit to identify interconnections between ports in a network.

Preferably, the apparatus includes a plurality of second coupling units, each second coupling unit being configured to couple to a respective second one of the plurality of cable lines and, if a respective second test signal is present in the respective second cable line, to couple the respective second test signal out from the respective second cable line.

Where there is a plurality of second coupling units, the signal processing unit is preferably configured to, if any one or more of the second coupling units couples out a respective second test signal, analyse one or more characteristics of the or each respective second test signal to determine, for at least one respective second test signal, based on the one or more analysed characteristics, which of the following conditions, if any, is true: (i) the respective second test signal is a direct signal that has propagated directly from a first coupling unit to a second coupling unit via a single cable line to which the first and second coupling units are coupled; (ii) the respective second test signal is a crosstalk signal that has propagated indirectly from a first coupling unit to the second coupling unit via one or more coupling paths between different cable lines to which the first and second coupling units are respectively coupled.

Here, it should be appreciated that a determination that condition (i) is true for a respective second test signal indicates that the respective second test signal has resulted from a first test signal that was coupled by a first coupling unit into a first cable line that is also the second cable line from which the respective second test signal was coupled out. Likewise, it should be appreciated that a determination that condition (ii) is true for a respective second test signal indicates that the respective second test signal has resulted from a first test signal that was coupled by a first coupling unit into a first cable line that is different from the second cable line from which the respective second test signal was coupled out.

In some embodiments, the signal processing unit may be configured to analyse only the one or more characteristics of a respective second test signal to determine, for that second test signal, whether condition (i) or (ii) is true. However, it is equally possible for the signal processing unit to be configured to analyse one or more characteristics of each of a plurality of respective second test signals to determine, for one or more of the respective second test signals, whether condition (i) or (ii) is true.

The determination by the signal processing unit of which, if any, of conditions (i) and (ii) is true for a second test signal may advantageously be used for operational or diagnostic purposes.

Preferably, the determination by the signal processing unit is used to identify interconnections between ports in a network including a plurality of cable lines. Accordingly, the test signal processing apparatus is preferably implemented as a network interconnection identification apparatus for identifying interconnections between ports in a network including a plurality of cable lines. To this end, the signal processing unit is preferably configured to, if it determines that a second test signal coupled out by a second coupling unit is a direct signal that has propagated directly from a first coupling unit to the second coupling unit via a single cable line to which the first and second coupling units are coupled, identify an interconnection between a first port associated with that first coupling unit and a second port associated with that second coupling unit. The or each first coupling unit may be associated or associable with a respective first port in a network and the or each second coupling unit may be associated or associable with a respective second port in the network.

The signal processing unit may additionally or alternatively be configured to, if it determines that a second test signal coupled out by a second coupling unit is a crosstalk signal, measure the magnitude of the crosstalk signal. The magnitude of the crosstalk signal could be measured using techniques well known to those skilled in the art of signal processing. The measured magnitude of the crosstalk signal could be used, for example, to determine if there is too much crosstalk between ports in a network. Too much crosstalk may be a symptom of cables running too close to each other, and could therefore indicate to a network operator that cables in the network need to be separated.

The first test signal generated by the signal generating unit may be any signal having characteristics such that, when the first test signal is coupled into one of a plurality of cables by a first coupling unit, the characteristics of a resulting second test signal coupled out from one of the plurality of cables by a second coupling unit can be analysed to determine whether the resulting second test signal is a direct signal or crosstalk signal. The present inventors have found that signals suitable for performing time domain reflectometry or frequency domain reflectometry are suitable. Accordingly, the signal generating unit may be configured to generate a first test signal suitable for performing time domain reflectometry and/or a first test signal suitable for performing frequency domain reflectometry.

In time domain reflectometry, a system response is measured as a function of time. A test signal suitable for time domain reflectometry might be, for example, an impulse or narrow transient test signal, e.g. having a duration of less than 10 ns (which corresponds to an electrical length of 2 meters).

In frequency domain reflectometry, a system response is measured as a function of frequency. A test signal suitable for frequency domain reflectometry might be, for example, a frequency swept sine wave or pseudo random noise. Frequency domain information can be converted into a corresponding time domain response via an inverse Fourier transform, as would be known to those skilled in the art.

Preferably, the signal generating unit is configured to generate a first test signal that is a voltage signal.

As would be appreciated by a person skilled in the art of signal processing, a large number of different characteristics of a second test signal could be analysed to determine whether a second test signal is a direct signal or a crosstalk signal. Some of these characteristics, and techniques for analysing these characteristics to distinguish between direct signals and crosstalk signals are discussed below with reference to FIGS. **16-21**.

For example, the one or more characteristics of the or each second test signal analysed by the signal processing unit may include any one or more of the following characteristics: the amplitude of the second test; the amplitude of the second test signal as measured at a plurality of frequencies; an amplitude-frequency characteristic of the second test signal; an amplitude-distance characteristic of the second test signal; and an amplitude-time characteristic of the second test signal. However, this list of characteristics is not thought by the present inventors to be exhaustive. For example, the one or more characteristics of the or each second test signal analysed by the signal processing unit may equally include any one or more of the phase of the second test signal; or the phase of the second test signal as measured at a plurality of frequencies.

For completeness, it is observed that as the velocity of a signal propagating along a cable is generally constant, time is proportional to distance and therefore an amplitude-distance characteristic can also be considered to be an amplitude-time characteristic.

In some embodiments, the signal generating unit may be configured to generate a first test signal of a first type and a first test signal of a second type. The first and second types of first test signal could, for example, be suitable for performing different types of analysis. Preferably, the signal processing unit is configured to analyse one or more characteristics of second test signals of the first type and second test signals of the second type.

Preferably, the first type of test signal is a frequency domain test signal and the second type of test signal is a frequency domain test signal, with the first type of test signal containing fewer frequency values than the second type of test signal. Thus, for example, the first test signal of the first type could be a frequency swept sine wave containing only eight different frequency values, with the first test signal of the second type being a frequency swept sine wave containing one hundred and twenty eight different frequency values.

If there is a plurality of the second coupling units, the signal processing unit may be configured to, if more than one of the second coupling units couples out a respective second test signal of a first type, analyse one or more characteristics of each respective second test signal of the first type to establish a shortlist of second coupling units, the shortlist including the second coupling units which are identified as having potentially coupled out a direct signal. In this case, the signal processing unit is preferably further configured to, if more than one of the shortlisted second coupling units couples out a respective second test signal of a second type, analyse one or more characteristics of each respective second test signal of the second type to determine which, if any, of the respective second test signals of the second type is a direct signal.

In this way, the time taken to determine which of a plurality of second coupling units has coupled out a direct signal can be reduced if, for example, analysis of the second type of test signal takes longer, but is more accurate than, the analysis of the first type of test signal. This might be the case, for example, if the first and second types of test signal are both frequency domain test signals, with the first type of test signal containing fewer frequency values than the second type of test signal, since a frequency domain test signal containing a larger number of frequency values will generally take longer to analyse but will generally permit a more accurate determination of whether that test signal is a direct signal or a crosstalk signal.

The plurality of cable lines with which the apparatus may be used could be any type of cable line in which the one or more cables each have at least two conductors. However, preferably, the plurality of cable lines each include one or more twisted pair cables, i.e. cables including a plurality of twisted pairs.

Preferably, the or each first coupling unit is configured to couple a respective first test signal generated by the signal generating unit into a respective first one of the plurality of cable lines such that the respective first test signal propagates along the respective first cable line between at least two twisted pairs in the respective first cable line. Also preferably, the or each second coupling unit is configured to couple a respective second test signal out from a respective second one of the plurality of cable lines after it has propagated between at least two twisted pairs in the respective second cable line.

Preferably, the or each first coupling unit is configured to couple a respective first test signal into a respective first one of the plurality of cable lines by non-contact coupling with the conductors of the respective first cable line. In this context, non-contact coupling refers to coupling that does not involve direct electrical (ohmic) contact with the conductors of the cable line. Likewise, the or each second coupling unit is preferably configured to couple a respective second test signal out from a respective second one of the plurality of cable lines by non-contact coupling with the conductors of the respective second cable line. However, it is equally possible, and would be within the capability of a person skilled in the art of signal processing, to instead use first and second coupling units configured to couple to cable lines by direct electrical (ohmic) contact with the conductors of the cable lines.

Coupling units capable of coupling a test signal generated by a signal generating unit into (or out from) a twisted pair cable line by non-contact coupling so that the signal propagates (or after the signal has propagated) between at least two twisted pairs in the twisted pair cable line are described below with reference to FIGS. **13**-**15**, and also in UK patent application number GB0905361.2, U.S. patent application Ser. No. 11/597,575 and International patent application number PCT/GB2010/000594, also by the present inventors.

Accordingly, the or each first coupling unit may include any one or more of the following features: first and second electrodes arranged to produce an electric field therebetween to couple a voltage signal (which may, for example, be a first test signal generated by the signal generating means) into a twisted pair cable by non-contact coupling with twisted pairs in the twisted pair cable so that the voltage signal propagates along the twisted pair cable between at least two of the twisted pairs; electrical isolation means (e.g. a balun) arranged to electrically isolate the electrodes from the signal generating unit; shielding for shielding the electrodes from an external electromagnetic field; means for converting (e.g. a choke) a single-ended voltage signal from a signal generating unit into a differential voltage signal to be coupled to the electrodes; and a housing which may be arranged to be clipped onto a twisted pair cable.

Likewise, the or each second coupling unit may include any one or more of the following features: first and second electrodes arranged to couple a voltage signal (which may, for example, be a second test signal resulting from a first test signal coupled into one of the plurality of cable lines by a first coupling unit) out from a twisted pair cable by non-contact coupling with at least two of the twisted pairs in the twisted pair cable between which the voltage signal has propagated; electrical isolation means (e.g. a balun) arranged to electrically isolate the electrodes from the signal processing unit; shielding for shielding the electrodes from an external electromagnetic field; means for converting (e.g. a choke) a differential voltage signal from the electrodes into a single-ended voltage signal to be coupled to a signal processing unit; a housing which may be arranged to be clipped onto a twisted pair cable.

The combination of the first and second electrodes with the electrical isolation means has been found to be particularly preferable for reducing crosstalk between twisted pair cables, as discussed in UK patent application number GB0905361.2, U.S. patent application Ser. No. 11/597,575 and International patent application number PCT/GB2010/000594, also by the present inventors.

In a second aspect, the present invention provides a signal processing method according to statement N.

The method may include any of the features, or method steps corresponding to the features, described in relation to the first aspect.

Accordingly, the method may, for example, include coupling, using each of a plurality of second coupling units, a respective second test signal out from a respective second one of the plurality of cable lines; and analysing one or more characteristics of each respective second test signal to determine, for at least one respective test signal, based on the one or more analysed characteristics, which, if any, of conditions (i) and (ii) is true.

Likewise, the method may, for example, further include: if it is determined that a second test signal coupled out by a second coupling unit is a direct signal that has propagated directly from a first coupling unit to the second coupling unit via a single cable line to which the first and second coupling units are coupled, identifying an interconnection between a first port associated with that first coupling unit and a second port associated with that second coupling unit.

The invention also includes any combination of the aspects and preferred features described except where such a combination is clearly impermissible or expressly avoided.

Embodiments of our proposals are discussed below, with reference to the accompanying drawings in which:

FIGS. **11***a* and **11***b* respectively show arrangements which illustrate a "direct signal" and a "crosstalk signal".

FIG. **12** shows a test signal processing apparatus implemented as a network interconnection identification apparatus.

FIGS. **13***a* and **13***b* show a pair of electrodes for coupling a voltage signal which propagates between twisted pairs into and out from a twisted pair cable.

FIG. **14** shows a coupling unit which may be used in the network interconnection identification apparatus of FIG. **12**.

FIGS. **15***a* and **15***b* respectively show a first coupling unit and circuitry associated with the first coupling unit for coupling a voltage signal into a twisted pair cable and a second coupling unit and circuitry associated with the second coupling unit for coupling a voltage signal out from a twisted pair cable.

FIG. **16** shows an experimental arrangement for demonstrating the different characteristics of direct signals and crosstalk signals.

FIG. **17** shows amplitude-frequency plots for a direct signal and a corresponding crosstalk signal produced using the apparatus of FIG. **16**.

FIGS. **18***a-c* are schematic diagrams showing a direct signal and a crosstalk signal produced using the apparatus of FIG. **16** in the time domain.

FIG. **19** shows theoretical amplitude-time plots for the direct signal and the crosstalk signal described with reference to FIG. **8**.

FIGS. **20***a* and **20***b* respectively show amplitude-time plots for a direct signal and a crosstalk signal produced using the apparatus of FIG. **16**.

FIGS. **21***a* and **21***b* respectively show amplitude-distance plots for a direct signal and a crosstalk signal produced using the apparatus of FIG. **16**.

FIG. **22** shows a typical patch system organised into a server row, a cross-connect row and a network row.

FIG. **11***a* shows an arrangement which illustrates a "direct signal". The arrangement of FIG. **11***a* includes a first cable line **110***a*, a first ("transmitter) coupling unit **120** and a second ("receiver") coupling unit **140**. The first coupling unit **120** is configured to couple to a first one of a plurality of cable lines and to couple a first test signal into that first cable line such that the first test signal propagates along that first cable line between at least two conductors in that first cable line. The second coupling unit **140** is configured to couple to a second one of a plurality of cable lines and, if a second test signal is present in that second cable line, to couple the second test signal out from that second cable line.

In FIG. **11***a*, both the first coupling unit **120** and the second coupling unit **140** are coupled to the same cable line, i.e. the first cable line **110***a*. Accordingly, a second test signal coupled out from the first cable line **110***a* by the second coupling unit **140** will have propagated directly from the first coupling unit **120** to the second coupling unit **140** via a single cable line. A test signal which has propagated in this way can therefore be referred to as a "direct signal".

FIG. **11***b* shows an arrangement which illustrates a "crosstalk signal". The arrangement of FIG. **11***b* is the same as that of FIG. **11***a*, except that there are additional second and third cables lines **110***b*, **110***c*, and the second coupling unit **140** is coupled to a different cable line from the first coupling unit **120**, i.e. to the second cable line **110***b* rather than the first cable line **110***a*. Accordingly, a second test signal coupled out from the second cable line **110***b* by the second coupling unit **140** will have propagated indirectly from the first coupling unit **120** to the second coupling unit **140** via one or more coupling paths between different cable lines. A test signal which has propagated in this way can therefore be referred to as a "crosstalk signal". The word "alien" may optionally be used to describe this crosstalk signal so as to indicate that the crosstalk occurs between different cable lines, rather than within a single cable line.

The one or more coupling paths between the first cable line **110***a* and the second cable line **110***b* are symbolically indicated in FIG. **11***b* by arrows. These coupling paths typically include unwanted capacitive and/or inductive coupling paths and may involve cable lines other than those to which the first coupling unit **120** and second coupling unit **140** are respectively coupled, e.g. the third cable line **110***c* shown in FIG. **11***b*.

Note that in FIGS. **11***a* and **11***b*, each of the first, second and third cable lines **110***a*, **110***b*, **110***c* includes a plurality cables (e.g. UTP cables) whose conductors are directly coupled together by appropriate connectors **112**, e.g. RJ-45 type connectors. However, each of the cable lines **110***a*, **110***b*, **110***c* could include only one cable. In either case, the crosstalk signal is different to the direct signal in that it has propagated between different cable lines via one or more (non-ohmic, e.g. capacitive or inductive) coupling paths.

FIG. **12** shows a test signal processing apparatus implemented as a network interconnection identification apparatus **200** for identifying interconnections between ports in a network including a plurality of cable lines.

FIG. **12** additionally shows a network including plurality of first cable lines **210***a-d* connected to a plurality of first ports **213***a-d* housed in a first patch panel **215***a*. The first cable lines **210***a-d* may, for example, lead to file servers and switches in a local area network. The network also includes plurality of second cable lines **210***e-h* connected to a plurality of second ports **213***e-h* housed in a second patch panel **215***b*. The first ports **213***a-d* and second ports **213***e-h* are interconnected by a plurality of patch cables **211**, although for clarity, only one of the patch cables **211** is shown in FIG. **12**.

The network interconnection identification apparatus **200** shown in FIG. **12** has a plurality of first coupling units **220***a-d* and a signal generating unit (not shown). The signal generating unit included in the network identification apparatus **200** may, for example, be as described below with reference to FIG. **15***a*.

Each first coupling unit **220***a-d* is coupled to a respective first cable line **210***a-d*, is associated with a respective port **213***a-d* in the first patch panel, and is configured to couple a respective first test signal generated by the signal generating unit into the respective first cable line **210***a-d* such that the respective first test signal propagates along the respective first cable line **210***a-d* between at least two conductors in the respective first cable line **210***a-d*.

The apparatus of FIG. **12** also has a plurality of second coupling units **240***a-d* and a signal processing unit (not shown). The signal processing unit included in the network identification apparatus **200** may, for example, be as described below with reference to FIG. **15***b*.

Each second coupling unit **240***a-d* is coupled to a respective second cable line **210***e-h*, is associated with a respective port **213***e-h* in the second patch panel **215***b*, and is configured to, if a respective second test signal is present in the respective second cable line **210***e-h*, to couple the respective second test signal out from the respective second cable line **210***e-h*. Typically, a respective second test signal coupled out from a respective second cable line **210***e-h* by one of the second coupling units **240***a-d* will have resulted from a first test signal coupled into a respective one of the first cable lines **210***a-d* by one of the first coupling units **220***a-d*.

The signal processing unit is configured to, if any one or more of the second coupling units **240***a-d* couples out a respective second test signal, analyse one or more characteristics of the or each respective second test signal to determine, for at least one respective second test signal, based on the one or more analysed characteristics, which of the following conditions, if any, is true:

(i) the respective second test signal is a direct signal that has propagated directly from a first coupling unit **220***a-d* to a second coupling unit **240***a-d* via a single cable line to which the first and second coupling units are coupled;

(ii) the respective second test signal is a crosstalk signal that has propagated indirectly from a first coupling unit **220***a-d* to the second coupling unit **240***a-d* via one or more coupling paths between different cable lines to which the first and second coupling units are respectively coupled.

Preferably, the signal processing unit is further configured to, if it determines that a second test signal coupled out by a second coupling unit **240***a-d* is a direct signal that has propagated directly from a first coupling unit **220***a-d* to the second coupling unit **240***a-d* via a single cable line to which the first and second coupling units are coupled, identify an interconnection between a first port associated with that first coupling unit **220***a-d* and a second port associated with that second coupling unit **240***a-d*.

The signal processing unit may additionally or alternatively be configured to, if it determines that a second test signal coupled out by a second coupling unit is a crosstalk signal, measure the magnitude of the crosstalk signal.

In some embodiments, the signal generating unit may be configured to generate a first test signal of a first type (e.g. a frequency domain test signal containing a relatively small number of frequency values, e.g. eight frequency values) and a first test signal of a second type (e.g. a frequency domain test signal containing a relatively large number of frequency values, e.g. one hundred and twenty eight frequency values). Preferably, the signal processing unit is configured to analyse one or more characteristics of second test signals of the first type and second test signals of the second type.

In some embodiments, the signal processing unit may be configured to, if more than one of the second coupling units **240***a-d* couples out a respective second test signal of the first type, analyse one or more characteristics of each respective second test signal of the first type to establish a shortlist of second coupling units **240***a-d*, the shortlist including the second coupling units **240***a-d* which are identified as having potentially coupled out a direct signal. The signal processing unit is preferably further configured to, if more than one of the shortlisted second coupling units **240***a-d* couples out a respective second test signal of a second type, analyse one or more characteristics of each respective second test signal of the second type to determine which, if any, of the respective second test signals of the second type is a direct signal.

In FIG. **12**, the first cable line **210***c* is shown as being connected to the second cable line **210***h* by the patch cable **211**, so the first and second cable lines **210***c*, **210***h* therefore form part of the same (single) cable line. Accordingly, the first coupling unit **210***c* and the second coupling unit **210***h* as shown in FIG. **12** as being coupled to the same cable line.

It should be appreciated that whilst FIG. **12** only shows four of each of the first cable lines **210***a-d*, the first ports **213***a-d*, the first coupling units **220***a-d*, the second cable lines **210***e-h*, the second ports **213***e-h*, and the second coupling units, a smaller or larger number of each of these items could easily be used according to network requirements.

FIGS. **13***a* and **13***b* show a pair of electrodes **322***a*, **322***b* for coupling a voltage signal which propagates between twisted pairs into and out from a twisted pair cable **310**. The pair of electrodes **322***a*, **322***b* may be used, for example, in one of the first coupling units **220***a-d* or one of the second coupling units **240***a-d* of the network interconnection identification apparatus **200** shown in FIG. **12**. The electrodes **322***a*, **322***b* shown in FIGS. **13***a* and **13***b* are also shown and described in UK patent application number GB0905361.2, U.S. patent application Ser. No. 11/597,575 and International patent application number PCT/GB2010/000594, also by the present inventors.

As shown in FIG. **13***a*, a first electrode **322***a* is provided in the form of a first plate and a second electrode **322***b* is provided in the form of a second plate. The electrodes **322***a*, **322***b* together form a capacitor. In this example, the plates forming the first and second electrodes **322***a*, **322***b* are approximately 20 mm long and 8 mm wide. The plates may be made of any suitable material e.g. copper foil.

The first and second electrodes **322***a*, **322***b* are spaced apart to allow the twisted pair cable **310** to be received therebetween, such that the electrodes **322***a*, **322***b* are located on directly opposite sides of the twisted pair cable **310**. Each of the plates forming the electrodes **322***a*, **322***b* has an inwardly curved (i.e. concave) contact surface for contacting a convex outer surface **314**, in this case the outer surface of an insulating sheath, of the twisted pair cable **310**. The curvature of the contact surfaces of the plates conform to the curvature of the convex outer surface **314** of the twisted pair cable **310** so that the electrodes **322***a*, **322***b* can be held in contact with the convex outer surface **314**.

To couple a voltage signal, e.g. from a signal generating unit, into the twisted pair cable **310** by non-contact coupling with the twisted pairs, the voltage signal may be coupled to the electrodes **322***a*, **322***b* so that a corresponding electric field **316** is produced between the electrodes **322***a*, **322***b*. Because the electric field **316** between the first and second electrodes **322***a*, **322***b* is different at twisted pairs **1-2** and **5-6**, a voltage is developed between twisted pairs **1-2** and **5-6** which corresponds to the voltage signal coupled to the electrodes **322***a*, **322***b*. In this way, the voltage signal can be coupled in to the cable **110** such that it propagates between at least twisted pairs **1-2** and **5-6**.

The electrodes **322***a*, **322***b* may additionally or alternatively be used to couple a voltage signal out from the twisted pair cable **310** by non-contact coupling with at least two of the twisted pairs between which the voltage signal has propagated, as shall now be described with reference to a voltage signal that is propagating between the twisted pairs **1-2** and **5-6**.

The voltage signal propagating between twisted pairs **1-2** and **5-6** of the cable **310** will have an electric field **316** between the twisted pairs **1-2** and **5-6** associated therewith. The electric field **316** may cause a voltage to be developed between the first and second electrodes **322***a*, **322***b* which corresponds to the voltage signal between the twisted pairs **1-2** and **5-6**. In this way, the voltage signal can be coupled out from the cable **310** by the electrodes **322***a*, **322***b*.

FIG. **13***b* shows the pair of electrodes **322***a*, **322***b* shown in FIG. **13***a*, along with another pair of electrodes **342***a*, **342***b*. Electrodes **322***a*, **322***b* may be used as the electrodes of a first coupling unit for coupling a voltage signal into the twisted cable **310** such that the signal propagates along the twisted pair cable **310** between at least two twisted pairs in the twisted pair cable **310**. Electrodes **342***a*, **342***b* may be used as the electrodes of a second coupling unit for coupling a voltage signal out from the twisted pair cable **310** after it has propagated along the twisted pair cable between at least two of the twisted pairs **310**.

FIG. **13***b* also shows the twisted pair cable **310** of FIG. **13***a* in more detail. As shown in FIG. **13***b*, not only is each twisted pair **1-2**, **3-4**, **5-6**, **7-8** twisted at a twist rate which is different to that of the other twisted pairs, but all of the twisted pairs are additionally twisted around each other. This is typical in a UTP cable.

Because all the twisted pairs **1-2**, **3-4**, **5-6**, **7-8** of the twisted pair cable **310** are twisted around each other, the electrodes **342***a*, **342***b* are not necessarily aligned to be adjacent to the same twisted pairs as the electrodes **322***a*, **322***b* of a first coupling unit which coupled a voltage signal into the twisted pair cable **310**. Consequently, the strength of the signal receivable by the electrodes **342***a*, **342***b* varies between maxima and minima according to their longitudinal position along the twisted pair cable **310**. Varying the circumferential position of the electrodes **342***a*, **342***b* has a similar effect.

In practice, the inventors have found that a signal of adequate strength can often be received irrespective of the longitudinal/circumferential position of the electrodes **342***a*, **342***b*. However, the above-described maxima and minima effect may lead to "null" locations on the twisted pair cable at which the electrodes **342***a*, **342***b* cannot couple out a voltage signal. Thus, it may be necessary to adjust the longitudinal/circumferential position of the electrodes **342***a*, **342***b* in order for these electrodes to receive (couple out) a voltage signal having a desired strength.

An alternative solution, which avoids the need to adjust the longitudinal/circumferential position of the electrodes **342***a*, **342***b* of the second coupling unit, is to have two pairs of electrodes, i.e. four electrodes in total, for coupling a voltage signal to and/or from the twisted pair cable **310** (not shown). For example, if there are two pairs of electrodes for coupling the voltage signal out from the twisted pair cable, an appropriate longitudinal separation between the two pairs of electrodes could be chosen to ensure that if the first pair of electrodes was in a "null" position, then the second pair of electrodes would be near a maximum. A detector and/or a switch could be used to allow the pair of electrodes receiving the largest voltage signal to be selected, e.g. by a signal processing unit.

FIG. **14** shows a coupling unit **420** which may be used in the network interconnection identification apparatus **200** of FIG. **12**, e.g. as a first or second coupling unit. The coupling unit **420** is capable of coupling a voltage signal, which may be a test signal, generated by a signal generating unit into (or out from) a twisted pair cable **410** by non-contact coupling so that the voltage signal propagates (or after the signal has propagated) between at least two twisted pairs in the twisted pair cable **410**. The coupling unit shown in FIG. **14** was also shown and described in UK patent application number GB0905361.2, U.S. patent application Ser. No. 11/597,575 and International patent application number PCT/GB2010/000594, also by the present inventors.

The coupling unit **420** includes a first electrode **422***a* and a second electrode **422***b*. The coupling unit **420** preferably includes a voltage signal coupling means which may include a first terminal **425***a*, a second terminal **425***b*, an electrical isolating means **424** in the form of a balun, and a converting means **426** in the form of a choke. The coupling unit **420** preferably includes shielding **429** in the form of an electrostatic screen which encloses the electrodes **422***a*, **422***b*, the electrical isolating means **424** and the converting means **426**, and is preferably connected to the local ground GND, e.g. via the second terminal **425***b*. A suitable balun for the electrical isolating means **122** may be Mini-Circuits® type MCL506T2-T1. A suitable choke for the converting means **124** may be Mini-Circuits® type MCL750T1-1.

To couple a voltage signal into a twisted pair cable **410**, the first terminal **425***a* may be connected to a signal generating unit (not shown). The second terminal **425***b* may be connected to a local ground GND for the signal generating unit.

A voltage signal generated by the signal generating unit may be a single-ended voltage signal which is converted into a differential voltage signal by the converting means **426**, e.g. the choke, in the manner known to those skilled in the art. For example, if the signal generating unit produced a sinusoidal voltage expressed (in complex phasor notation) as $V \cdot \exp(j\omega t)$; then the voltages outputted by the converting means **426** may be expressed as $V \cdot \exp(j\omega t)/2$ and $-V \cdot \exp(j\omega t)$. The differential voltage signal from the converting means **426** is then coupled to the electrodes **422***a*, **422***b* via the electrical isolating means **424**, which electrically isolates the electrodes **422***a*, **422***b* from the signal generating unit.

The electrodes **422***a*, **422***b* of the coupling unit **420** may be the same as the electrodes described with reference to FIGS. **13***a* and **13***b*, and may couple the voltage signal into the twisted pair cable **410** in the same manner.

As explained in UK patent application number GB0905361.2, U.S. patent application Ser. No. 11/597,575 and International patent application number PCT/GB2010/000594, also by the present inventors, the inventors have found that a voltage signal which propagates along a twisted pair cable between two of the twisted pairs can propagate reliably and over useful distances, without significantly altering the transmission of signals within the individual twisted pairs. In particular, the inventors have found that coupling a voltage signal to a twisted pair cable using electrically isolated electrodes can help to reduce leakage of the voltage signal from the cable, e.g. through neighbouring twisted pair cables.

To couple a voltage signal out from the twisted pair cable **410**, the first terminal **425***a* may be connected to a signal processing unit (not shown). The second terminal **425***b* may be connected to a local ground GND for the signal processing unit.

The electrodes **422***a*, **422***b* of the coupling unit **420** may be the same as the electrodes described with reference to FIGS. **13***a* and **13***b*, and may couple a voltage signal out from the twisted pair cable **410** in same manner. The voltage signal coupled out from the twisted pair cable **410** can then be coupled to the signal processing unit via the electrical isolating means **426** and the converting means **426**. The voltage signal received by the electrodes **422***a*, **422***b* may be a differential voltage signal which may be converted to a single-ended voltage by the converting means **426**, e.g. the choke, in the manner known to those skilled in the art.

FIG. **15***a* shows a first coupling unit **520** and circuitry associated with the first coupling unit **520** for coupling a voltage signal, e.g. a first test signal, into a twisted pair cable **510**. The first coupling unit **520** may be used in the network interconnection identification apparatus **200** shown in FIG. **12**.

As shown in FIG. **15***a*, the first coupling unit **520** includes a pair of electrodes **522***a*, **522***b*, an electrical isolating means **524** in the form of a balun, a converting means **526** in the form of a choke, an amplifier **528**, and shielding **529**. The electrodes **522***a*, **522***b*, the electrical isolating means **524** and the converting means **526** may be as described above with reference to FIGS. **13** and **14**. The shielding **529** shields the electrodes **522***a*, **522***b* from external electromagnetic fields, e.g. from other nearby twisted pair cables and nearby coupling units.

The coupling unit **520** preferably has a housing (not shown) arranged to be clipped on to the twisted pair cable **510** (e.g. by way of a suitable channel in the coupling unit or suitable retention lugs) such that the pair of electrodes **522***a*, **522***b* contact directly opposite sides of an outer surface of the twisted pair cable **510**. The housing may include some or all of the components of the second coupling unit **540**.

The circuitry associated with the first coupling unit **520** preferably includes one or more of a direct signal synthesizer **530**, a field programmable gate array **532**, and a processor **536**, all of which are preferably connected as shown in FIG. **15***a*. The processor **536** may be connected to, and controlled by, a control unit (not shown) by way of a serial link **538**. The direct signal synthesizer **530**, field programmable gate array **532** and processor **536** may be shared by a plurality of the first coupling units **520**, e.g. in a network interconnection identification apparatus such as that shown in FIG. **12**.

The circuitry associated with the first coupling unit **520** forms a signal generating unit configured to generate a voltage signal, e.g. a first test signal, to be coupled to a twisted pair cable **510** by the electrodes **522***a*, **522***b* of the coupling unit **520**. The signal generating unit may be used, for example, with the network interconnection identification apparatus **200** shown in FIG. **12**.

In operation, the direct signal synthesizer **530** is preferably controlled by the field programmable gate array **532** and processor **536** to generate a voltage signal, e.g. a single-ended voltage signal to be supplied to the coupling unit **520**. Once generated, the single-ended voltage signal from the direct signal synthesiser **530** is amplified by the amplifier **528**, and is then converted into a differential voltage signal and coupled to the twisted pair cable **510** by the converting means **524**, the electrical isolating means **522** and the first pair of electrodes **522***a*, **522***b* of the coupling unit **520** in the manner described above with reference to FIGS. **13** and **14**, i.e. such that the voltage signal propagates between at least two of the twisted pairs in the twisted pair cable **510**.

FIG. **15***b* shows a second coupling unit **540** and circuitry associated with the second coupling unit **540** for coupling a voltage signal, e.g. a second test signal, out from a twisted pair cable **510**. The second coupling unit **540** may be used e.g. in the apparatus shown in FIG. **12**.

As shown in FIG. **15***b*, the second coupling unit **540** includes a pair of electrodes **542***a*, **542***b*, an electrical isolating means **544** in the form of a balun, a converting means **546** in the form of a choke, an amplifier **548**, and shielding **549**. The electrodes **542***a*, **542***b*, the electrical isolating means **524** and the converting means **526** may be as described above with reference to FIGS. **13** and **14**. As with the first coupling unit shown in FIG. **15***a*, the shielding **549** shields the electrodes **542***a*, **542***b* from external electromagnetic fields, e.g. from other nearby twisted pair cables and nearby coupling units.

As with the first coupling unit shown in FIG. **15***a*, the second coupling unit **540** preferably has a housing (not shown) arranged to be clipped on to the twisted pair cable **510** (e.g. by way of a suitable channel in the coupling unit or suitable retention lugs) such that the pair of electrodes **522***a*, **522***b* contact directly opposite sides of an outer surface of the twisted pair cable **510**. The housing may include some or all of the components of the first coupling unit **520**.

The circuitry associated with the second coupling unit **540** preferably includes one or more of a multiplier **549**, a direct signal synthesizer **550**, a field programmable gate array **552**, a low pass filter and amplifier **554**, an analogue to digital converter **555** and a processor **556**, all of which are preferably connected as shown in FIG. **15***b*. The processor **556** may be connected to, and controlled by, a control unit (not shown) by way of a serial link **558**. The direct signal synthesizer **550**, the field programmable gate array **552**, the low pass filter and amplifier **554**, the analogue to digital converter **555**, and the processor **556** may be shared by a plurality of the second coupling units **540**, e.g. in a network interconnection identification apparatus such as that shown in FIG. **12**.

The circuitry associated with the second coupling unit **540**, including the processor **556**, forms a signal processing unit configured to analyse one or more characteristics of a voltage signal, e.g. a second test signal, coupled out by the second coupling unit **540**. The signal processing unit may be used, for example, with the network interconnection identification apparatus **200** shown in FIG. **12**.

In operation, when a voltage signal which propagates between twisted pairs propagates along the twisted pair cable **510** to the second coupling unit **540**, the voltage signal is coupled out of the twisted pair cable **510** and converted into a single-ended voltage signal by the pair of electrodes **542***a*, **542***b*, the electrical isolating means **544** and the converting means **546** of the coupling unit **540** in the manner described above with reference to FIGS. **13** and **14**. The single-ended voltage signal is then amplified by the amplifier **548**, demodulated by the multiplier **549** and the low pass filter and amplifier **554** and is then passed to the analogue to digital converter **550** where it is converted into a digital signal. A final stage of demodulation is performed by the field programmable gate array **552** and the digital signal is then passed to the processor **556**.

A plurality of the first coupling units **520** shown in FIG. **15***a* may be used as first coupling units in the network interconnection identification apparatus **200** shown FIG. **12**, with the associated circuitry shown in FIG. **15***a* being used as the signal generating unit for generating a first test signal. Similarly, a plurality of the second coupling units **540** shown in FIG. **15***b* may be used as second coupling units in the network interconnection identification apparatus **200** shown in FIG. **12**, with the associated circuitry shown in FIG. **15***b* being used as the signal processing unit for determining, for at least one respective test signal, which of conditions (i) and (ii), if any, is true. This determination could, for example, be made by the processor **556**.

As would be appreciated by a person skilled in the art of signal processing, a large number of different characteristics of a second test signal could be analysed by the signal processing unit to determine whether a second test signal is a direct signal or a crosstalk signal. Some of these characteristics, and techniques for analysing these characteristics to distinguish between direct signals and crosstalk signals will now be discussed, with reference to FIGS. **16-21**.

FIG. **16** shows an experimental arrangement **600** for demonstrating the different characteristics of direct signals and crosstalk signals.

The experimental arrangement **600** shown in FIG. **16** has first and second cables **610***a*, **610***b*, which are separate and unterminated lengths of category 5 UTP cable that have been taped closely together by tape **616**.

A first coupling unit **620**, which has features corresponding to the first coupling unit **520** shown in FIG. **15***a*, is coupled to the first cable **610***a* to allow the first coupling unit **620** to couple a first test signal into the first cable **610***a*. Two second coupling units **640***a*, **640***b*, each having features corresponding to the second coupling unit **540** shown in FIG. **15***b*, are each coupled to a respective one of the first and second cables **610***a*, **610***b* at an opposite end from the first coupling unit **620**. The second coupling unit **640***a* is attached to the first cable **610***a*, i.e. the same cable as the first coupling unit **620**, and therefore will couple out a second test signal that is a direct signal. The other of the second coupling units **640***b* is attached to the second cable **610***b*, i.e. a different cable from the cable to which the first coupling unit **620** is coupled, and will therefore couple out a second test signal that is a crosstalk signal.

FIG. **17** shows amplitude-frequency plots for a direct signal **760** and a crosstalk signal **780** produced using the apparatus **600** of FIG. **16**. To produce the plot shown in FIG. **17**, category 5 UTP cables of length 2 meters were used as the first and second cables **600***a*, **600***b*. The first test signal coupled into the first cable **610***a* was a wideband frequency sweep from 956 kHz to 300 MHz containing approximately 1000 different frequencies. The phase and magnitude of the second test signal coupled out by the second coupling units **640***a*, **640***b* were recorded. The recorded phase and magnitude data was used directly to produce the amplitude-frequency plots of FIG. **17**.

As shown in FIG. **17**, the average (e.g. root mean square) amplitude (energy) of the direct signal **760** generally higher than that of the crosstalk signal **780**. Therefore, the amplitude of a second test signal coupled out by a second coupling unit at a selected frequency is indicative of whether that second test signal is a direct signal or a crosstalk signal.

Accordingly, the one or more characteristics of a second test signal analysed by a signal processing unit to determine whether that second test signal is a direct signal or a crosstalk signal may include the amplitude of the second test signal.

As would be appreciated by a person skilled in the art of signal processing, there are a large number of possible techniques for analysing the amplitude of a second test signal to determine whether that second test signal is a direct signal or a crosstalk signal.

A potential issue with analysing the amplitude of a test signal to distinguish between direct and crosstalk signals is illustrated by FIG. **17**. Here, the respective amplitudes of the direct signal **760** and the crosstalk signal **790** (particularly the crosstalk signal **780**) are strongly dependent on frequency. Thus, whilst the amplitude of the direct signal **760** is larger than the amplitude of the crosstalk signal **780** for most frequencies, there are certain frequencies at which the amplitude of the crosstalk signal **780** is larger than the amplitude of the direct signal **760** (see the circled portions of FIG. **17**). For a given cable, these certain frequencies typically correspond to values of the resonant frequencies of the cable, which are determined by the length and termination conditions of the cable. The amplitude of the crosstalk signal may therefore be higher where the resonances in the first and second cables **610***a*, **610***b* overlap.

To address this issue, in a presently preferred technique, the one or more characteristics of a second test signal analysed by a signal processing unit to determine whether that second test signal is a direct signal or a crosstalk signal include the amplitude of the second test signal as measured at a plurality of frequencies.

For example, the amplitude of the second test signal could be measured at nine different frequencies **790**, as shown in FIG. **17**. Preferably, the frequencies **790** are non-integer multiples of each other, in order to avoid harmonics. Preferably, the different frequencies **790** are in the range 30 to 150 MHz. The amplitude of the second test signal measured at each frequency could, for example, be combined (e.g. using a weighted sum) to create a parameter which characterises the overall amplitude of the signal over a frequency range. If the parameter exceeds an upper threshold, then the second test signal could be determined to be a direct signal. If the parameter is below a lower threshold, then the second test signal could be determined to be a crosstalk signal. If the parameter was in between the upper and lower thresholds, then the second coupling unit that coupled out the second test signal could be shortlisted as having potentially coupled out a direct signal. Suitable upper and/or lower thresholds could be determined empirically.

As illustrated by FIG. **17**, the amplitude-frequency plot for the direct signal **760** has a different shape to the amplitude-frequency plot for the cross-talk signal **780**. In particular, the amplitude-frequency plot for the crosstalk signal **780** has sharper resonances, which reflect, for example, cable length and the coupling paths between the first and second cables **610***a*, **610***b*.

Accordingly, the one or more characteristics of a second test signal analysed by a signal processing unit to determine whether that second test signal is a direct signal or a crosstalk signal may include an amplitude-frequency characteristic of the test signal, e.g. a parameter which reflects the shape of an amplitude-frequency plot for the test signal.

FIGS. **18***a-c* are schematic diagrams showing a direct signal **860** and a crosstalk signal **880** produced using the apparatus **600** of FIG. **16** in the time domain. To produce the signals depicted in FIGS. **18***a-c*, a transient first test signal including one cycle of a sine wave is assumed to have been coupled into the first cable **610***a* by the first coupling unit **620**. The transient first test signal could be generated, for example, using a frequency sweep and Fourier analysis techniques, which are known in the art.

FIGS. **18***a-c* show a plurality of coupling paths **619** between the first cable **610***a* and the second cable **610***b*, via which energy coupled into the first cable **610***a* may propagate into the second cable **610***b*. In FIG. **18**, the coupling paths **619** are depicted as capacitive coupling paths.

As shown in FIG. **18***b*, the direct signal **860** propagates along the first cable **610***a* in both directions and the passage of the direct signal along the first cable **610***a* is recorded at the second coupling unit **640***a*. If the cable is long (such as tens of meters) or is terminated with resistors that are impedance matched to the characteristic impedance of the cable, and in addition, if the cable has no discontinuities such as connectors, then the direct signal **860** will propagate without significant reflections, and will simply attenuate with distance, as shown in FIG. **18***b*.

As shown in FIG. **18***c*, the crosstalk signal **880** is coupled into the second cable **610***b* in a distributed manner via the coupling paths **619** along the length thereof. Accordingly, the crosstalk signal **880** received by the second coupling unit **640***b* is dispersed over a longer period of time, as shown in FIG. **18***c*. The crosstalk signal will be stronger if the first and second cables **610***a*, **610***b* have a similar construction.

FIG. **19** shows theoretical amplitude-time plots for the direct signal **860** and the crosstalk signal **880** described with reference to FIG. **18**.

As shown in the upper plot of FIG. **19**, the direct signal **860** tends to attenuate with time. This is because all the energy from the transient first test signal is coupled into the first cable **610***a* cable over a relatively short interval of time. The direct signal **860** therefore propagates along the first cable **610***a* in both directions. Reflections are caused by changes in impedance along the cable, but overall the magnitude of the signal decays in time as the energy coupled by the transmitter dissipates in the cable due to resistive, capacitive and inductive losses.

As shown in the lower plot of FIG. **19**, the crosstalk signal **880** behaves differently to the direct signal **860**. Here, energy from the transient first test signal is coupled into the second cable **610***b* over a period of time and the coupling is distributed over the length of the second cable **610***b*. Consequently, the crosstalk signal **880** builds up over an initial period as the transient test signal propagates forward and backward along the second cable **610***b*.

After a period of time both the direct signal **860** and the crosstalk signal **880** decay to zero as the energy dissipates due to resistive, capacitive and inductive losses in the first and second cables **610***a*, **610***b*.

FIGS. **20***a* and **20***b* respectively show amplitude-time plots for a direct signal **1060** and a crosstalk signal **1080** produced using the apparatus **600** of FIG. **16**. The amplitude-time plots of FIGS. **20***a* and **20***b* were produced by using a Fourier transform to transform the phase and magnitude data recorded to produce the plots of FIG. **17**, for which category 5 UTP cables of length 2 meters were used.

FIG. **20***a* clearly shows the amplitude of the direct signal **1060** decaying over time. FIG. **20***b* shows that, in contrast to the direct signal **1060**, the amplitude of the crosstalk signal **1080** initially builds up, this initial build up being followed by a gradual decay over the remaining period.

As can be seen from FIGS. **18**-**20**, the amplitude-time characteristics for a direct signal are different to the amplitude-time characteristics for a crosstalk signal. In particular, a crosstalk signal is dispersed over a longer period of time than a direct signal, and a crosstalk signal builds-up gradually and then decays rather than simply decaying in the manner of a direct signal.

Accordingly, the one or more characteristics of a second test signal analysed by a signal processing unit to determine whether that second test signal is a direct signal or a crosstalk signal may include an amplitude-time characteristic of the test signal.

As would be appreciated by a person skilled in the art of signal processing, there are a large number of possible techniques for analysing one or more amplitude-time characteristics of a second test signal to determine whether that second test signal is a direct signal or a crosstalk signal.

A presently preferred technique involves calculating the root mean square of the amplitude of the second test signal for each of a plurality of time intervals. In other words, the amplitude-time characteristic of the second test signal may include the root mean square of the amplitude of the second test signal as calculated for each of a plurality of time intervals.

For the data recorded in FIGS. **20***a* and **20***b*, the root mean square of the amplitude of the second test signals was calculated for eleven time intervals of duration 50 ns, starting from 0 ns as marked in FIGS. **20***a* and **20***b* (i.e. from 0 ns to 50, 50 ns to 100 ns and so on with the last time interval being 500 ns to 550 ns). A direct signal will have the largest root mean square value during the first 50 ns time interval than in subsequent time intervals. The crosstalk signal on the other hand will have a different profile, with the largest root mean square value not being during the first 50 ns time interval.

FIGS. **21***a* and **21***b* respectively show amplitude-time plots for a direct signal **1160** and a crosstalk signal **1180** produced using the apparatus **600** of FIG. **16**. To produce the plot shown in FIG. **21**, category 5 UTP cables of length 90 meters were used. The first test signal coupled into the first cable **610***a* was a transient first test signal including several cycles of a sine wave, and was produced using a frequency sweep and Fourier analysis techniques, which are known in the art.

As shown in FIG. **21**, the direct signal **1160** has a large initial amplitude. In addition a reflection **1190** from an end of the first cable **610***a* is also visible. The shape of the direct signal **1160** is consistent with the transient first test signal. The crosstalk signal **1180** on the other hand has lower overall amplitude, and does not display a shape consistent with a signal that has propagated along a single cable line.

As can be seen from FIG. **21**, the amplitude-time characteristics for a direct signal are different to the amplitude-time characteristics for a crosstalk signal. In particular, the crosstalk signal **1180** is dispersed over a longer period of time than the direct signal.

As already noted above, the one or more characteristics of a second test signal analysed by a signal processing unit to determine whether that second test signal is a direct signal or a crosstalk signal may include an amplitude-time characteristic of the second test signal.

Another possible technique for analysing one or more amplitude-time characteristics of a second test signal to determine whether that second test signal is a direct signal or a crosstalk signal involves cross-correlating each of a plurality of second test signals coupled out by second coupling units with a reference signal known to be a direct signal. Cross-correlating a direct signal would produce a peak in the cross-correlated signal. The position of the peak on the time axis would correspond to the time of propagation of the signal from the first coupling unit to the second coupling unit. As the speed of propagation for the cable is constant, this would correspond to the electrical length of the cable between the two coupling units. Cross-correlating a crosstalk signal would produce a cross-correlated signal having values close to zero. A threshold, e.g. determined empirically, could be applied to the cross-correlated signal to determine whether each second test signal coupled out by the second coupling units is a direct signal or a crosstalk signal.

Where the length of the cable lines **610***a*, **610***b* is short compared to the length of the transient test signal coupled into the first cable line **610***a* by the first coupling unit **620**, for example just several meters, the multiple reflections from any unterminated ends of the cable and from discontinuities may start to overlap. In this case, the time domain response becomes more complicated than that shown in FIG. **21** (as illustrated e.g. by FIGS. **20***a* and **20***b*). Nevertheless, even in these cases, it has been found that a direct signal can still be clearly differentiated from a crosstalk signal.

When used in this specification and statements, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or integers.

The features disclosed in the foregoing description, or in the following statements, or in the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for obtaining the disclosed results, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure, without departing from the broad concepts disclosed. It is therefore intended that the scope of the patent granted hereon be limited only by the appended statements, as interpreted with reference to the description and drawings, and not by limitation of the embodiments described herein.

STATEMENTS

A. A signal processing apparatus for use with a plurality of cable lines, the signal processing apparatus having:

a signal generating unit configured to generate a first test signal;

a first coupling unit configured to couple to a first one of the plurality of cable lines and to couple a first test signal generated by the signal generating unit into the first cable line such that the first test signal propagates along the first cable line between at least two conductors in the first cable line;

a second coupling unit configured to couple to a second one of the plurality of cable lines and, if a second test signal is present in the second cable line, to couple the second test signal out from the second cable line; and

a signal processing unit configured to, if the second coupling unit couples a second test signal out from a second one of the plurality of cable lines, analyse one or more characteristics of the second test signal to determine, based on the one or more analysed characteristics, which of the following conditions, if any, is true:

(i) the second test signal is a direct signal that has propagated directly from the first coupling unit to the second coupling unit via a single cable line to which the first and second coupling units are coupled;

(ii) the second test signal is a crosstalk signal that has propagated indirectly from the first coupling unit to the second coupling unit via one or more coupling paths between different cable lines to which the first and second coupling units are respectively coupled.

B. A signal processing apparatus according to statement A wherein:

the apparatus has a plurality of first coupling units, each first coupling unit being configured to couple to a respective first one of the plurality of cable lines and to couple a respective first test signal generated by the signal generating unit into the respective first cable line such that the respective first test signal propagates along the respective first cable line between at least two conductors in the respective first cable line;

the apparatus has a plurality of second coupling units, each second coupling unit being configured to couple to a respective second one of the plurality of cable lines and, if a respective second test signal is present in the respective second cable line, to couple the respective second test signal out from the respective second cable line;

the signal processing unit is configured to, if any one or more of the second coupling units couples out a respective second test signal, analyse one or more characteristics of the or each respective second test signal to determine, for at least one respective second test signal, based on the one or more analysed characteristics, which of the following conditions, if any, is true:

(i) the respective second test signal is a direct signal that has propagated directly from a first coupling unit to a second coupling unit via a single cable line to which the first and second coupling units are coupled;

(ii) the respective second test signal is a crosstalk signal that has propagated indirectly from a first coupling unit to the second coupling unit via one or more coupling paths between different cable lines to which the first and second coupling units are respectively coupled.

C. A test signal processing apparatus according to statement A or B wherein:

the signal processing unit is configured to, if it determines that a second test signal coupled out by a second coupling unit is a direct signal that has propagated directly from a first coupling unit to the second coupling unit via a single cable line to which the first and second coupling units are coupled, identify an interconnection between a first port associated with that first coupling unit and a second port associated with that second coupling unit.

D. A test signal processing apparatus according to any one of the previous statements wherein the signal processing unit is configured to, if it determines that a second test signal coupled out by a second coupling unit is a crosstalk signal, measure the magnitude of the crosstalk signal.

E. A test signal processing apparatus according to any one of the previous statements wherein the signal generating unit is configured to generate a first test signal suitable for performing time domain reflectometry and/or a first test signal suitable for performing frequency domain reflectometry.

F. A test signal processing apparatus according to any one of the previous statements wherein the one or more characteristics of the or each second test signal analysed by the signal processing unit may include any one or more of the following characteristics:

the amplitude of the second test signal;

the amplitude of the second test signal as measured at a plurality of frequencies;

the phase of the second test signal;

the phase of the second test signal as measured at a plurality of frequencies;

an amplitude-frequency characteristic of the second test signal;

an amplitude-distance characteristic of the second test signal; and

an amplitude-time characteristic of the second test signal.

G. A test signal processing apparatus according to any one of the previous statements wherein:

the signal generating unit is configured to generate a first test signal of a first type and a first test signal of a second type.

H. A test signal processing apparatus according to any one of the previous statements wherein:

there is a plurality of the second coupling units;

the signal processing unit is configured to, if more than one of the second coupling units couples out a respective second test signal of a first type, analyse one or more characteristics of each respective second test signal of the first type to establish a shortlist of second coupling units, the shortlist including the second coupling units which are identified as having potentially coupled out a direct signal; and

the signal processing unit is further configured to, if more than one of the shortlisted second coupling units couples out a respective second test signal of a second type, analyse one or more characteristics of each respective second test signal of the second type to determine which, if any, of the respective second test signals of the second type is a direct signal.

I. A test signal processing apparatus according to any one of the previous statements wherein the plurality of cable lines each include one or more twisted pair cables.

J. A test signal processing apparatus according to statement **9** wherein:

the or each first coupling unit is configured to couple a respective first test signal generated by the signal generating unit into a respective first one of the plurality of cable lines such that the respective first test signal propagates along the respective first cable line between at least two twisted pairs in the respective first cable line; and

the or each second coupling unit is configured to couple a respective second test signal out from a respective second one of the plurality of cable lines after it has propagated between at least two twisted pairs in the respective second cable line.

K. A test signal processing apparatus according to any one of the previous statements wherein:

the or each first coupling unit is configured to couple a respective first test signal into a respective first one of the plurality of cable lines by non-contact coupling with the conductors of the respective first cable line; and/or

the or each second coupling unit is preferably configured to couple a respective second test signal out from a respective second one of the plurality of cable lines by non-contact coupling with the conductors of the respective second cable line.

L. A test signal processing apparatus according to any one of the previous statements wherein the or each first coupling unit includes:

first and second electrodes arranged to produce an electric field therebetween to couple a voltage signal into a twisted pair cable by non-contact coupling with twisted pairs in the twisted pair cable so that the voltage signal propagates along the twisted pair cable between at least two of the twisted pairs; and

electrical isolation means arranged to electrically isolate the electrodes from the signal generating unit.

M. A test signal processing apparatus according to any one of the previous statements wherein the or each second coupling unit includes:

first and second electrodes arranged to couple a voltage signal out from a twisted pair cable by non-contact coupling with at least two of the twisted pairs in the twisted pair cable between which the voltage signal has propagated; and

electrical isolation means arranged to electrically isolate the electrodes from the signal processing unit.

N. A signal processing method including:

generating a first test signal;

coupling, using a first coupling unit, the first test signal into a first one of a plurality of cable lines such that the first test signal propagates along the first cable line between at least two conductors in the first cable line;

coupling, using a second coupling unit, a second test signal out from the second cable line; and

analysing one or more characteristics of the second test signal to determine, based on the one or more analysed characteristics, which of the following conditions, if any, is true:

(i) the second test signal is a direct signal that has propagated directly from the first coupling unit to the second coupling unit via a single cable line to which the first and second coupling units are coupled;

(ii) the second test signal is a crosstalk signal that has propagated indirectly from the first coupling unit to the second coupling unit via one or more coupling paths between different cable lines to which the first and second coupling units are respectively coupled.

O. A signal processing method according to statement N, wherein the method further includes if it is determined that a second test signal coupled out by a second coupling unit is a direct signal that has propagated directly from a first coupling unit to the second coupling unit via a single cable line to which the first and second coupling units are coupled, identifying an interconnection between a first port associated with that first coupling unit and a second port associated with that second coupling unit.

P. A signal processing apparatus substantially as any one embodiment herein described with reference to and as shown in the accompanying drawings.

Q. A signal processing method substantially as any one embodiment herein described with reference to and as shown in the accompanying drawings.

The invention claimed is:

1. An apparatus for identifying interconnections in a network comprising a plurality of cable lines, the apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective one of the plurality of cable lines in the network and to couple a test signal into the respective cable line coupled to the transmitter coupling unit;

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to the respective one of the plurality of cable lines or another respective one of the plurality of cable lines in the network and, if the test signal is present in the respective cable line, to couple the test signal out from the respective cable line coupled to the receiver coupling unit; and

an interconnection identification device configured to, if any one of the transmitter coupling units is coupled to the same cable line as a selected one of the receiver coupling units, identify an interconnection between the transmitter coupling unit and the selected receiver coupling unit by:

(i) selecting a subset of the transmitter coupling units;

(ii) conveying, at least once, the same test signal to each of the transmitter coupling units in the selected subset at substantially the same time so that, for each of the transmitter coupling units in the selected subset that is coupled to one of the plurality of cable lines, the transmitter coupling unit couples the test signal into the respective cable line coupled thereto;

(iii) determining whether one of the transmitter coupling units of the selected subset of transmitter coupling units is coupled to the same cable line as the selected receiver coupling unit based on whether the selected receiver unit couples out, from the cable line to which it is coupled, the test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset; and

(iv) selecting a new subset of the transmitter coupling units based on the determination in step (iii), and performing steps (ii) and (iii) for the newly selected transmitter coupling units; and

(v) if necessary, repeating step (iv) until the interconnection between one of the transmitter coupling units and the selected receiver coupling unit is identified.

2. The apparatus according to claim 1, wherein the interconnection identification device may be configured to identify either the interconnection between one of the transmitter coupling units and the selected receiver coupling unit or an absence of such interconnection by:

(i) selecting a subset of the transmitter coupling units;

(ii) conveying, at least once, the same test signal to each of the transmitter coupling units in the selected subset at substantially the same time so that, for each of the transmitter coupling units in the selected subset that is coupled to one of the plurality of cable lines, the transmitter coupling unit couples the test signal into the respective cable line coupled thereto;

(iii) determining whether one of the transmitter coupling units of the selected subset of transmitter coupling units is coupled to the same cable line as the selected receiver coupling unit based on whether the selected receiver unit couples out, from the cable line to which it is coupled, the test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset; and

(iv) selecting a new subset of the transmitter coupling units based on the determination in step (iii), and performing steps (ii) and (iii) for the newly selected transmitter coupling units; and

(v) if necessary, repeating step (iv) until an interconnection between one of the transmitter coupling units and the selected receiver coupling unit or the absence of such an interconnection is identified.

3. The apparatus according to claim 1, wherein the interconnection identification device is further configured so that, if it is determined in step (iii) that one of the transmitter coupling units of the selected subset of transmitter coupling units is coupled to the same cable line as the selected receiver coupling unit, then step (iv) includes:

(a) disregarding any transmitter coupling units that are not selected for the selecting of any new subsets of the transmitter coupling units; and

(b) selecting a subset of the previously selected transmitter coupling units as the new subset of the transmitter coupling units.

4. The apparatus according to claim 3, wherein step (b) includes selecting a subset which contains half of the previously selected transmitter coupling units as the new subset of the transmitter coupling units.

5. The apparatus according to claim 1, wherein the interconnection identification means is further configured so that, if it is determined in step (iii) that none of the transmitter coupling units of the selected subset of transmitter coupling units is coupled to the same cable line as the selected receiver coupling unit, then step (iv) includes:

(a) disregarding any transmitter coupling units that are selected for the selecting of any new subsets of the transmitter coupling units; and

(b) selecting all or a subset of the not selected and not disregarded transmitter coupling units as the new subset of the transmitter coupling units.

6. The apparatus according to claim 5, wherein step (b) includes selecting a subset which contains half of the not selected and not previously disregarded transmitter coupling units.

7. The apparatus according to claim 1, wherein the selecting of a new subset of the transmitter coupling unit in step (iv) based on the determination in step (iii) is made according to a binary tree search algorithm.

8. The apparatus according to claim 1, wherein the interconnection identification device includes a signal processing unit configured to, if any of the receiver coupling units couples out the test signal, analyse one or more characteristics of the coupled out test signal to determine, based on the one or more analysed characteristics, whether the coupled out test signal has propagated directly to the receiver coupling unit from one of the transmitter coupling units.

9. The apparatus according to claim 8, wherein the signal processing unit is configured to analyse one or more characteristics of the test signal to determine, based on the one or more analysed characteristics, which of the following conditions is true:

(i) the test signal is a direct signal which has propagated directly from one of the transmitter coupling units to the receiver coupling unit via a single cable line to which the transmitter and receiver coupling units are respectively coupled;

(ii) the test signal is a crosstalk signal that has propagated indirectly from one of the transmitter coupling units to the receiver coupling unit via one or more coupling paths between different cable lines to which the transmitter and receiver coupling units are respectively coupled.

10. The apparatus according to claim 9, wherein in step (iii), the signal processing unit is used to determine whether the selected receiver unit couples out, from the cable line to which it is coupled, the test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset.

11. The apparatus according claim 1, wherein:

each transmitter coupling unit includes two pairs of electrodes for coupling a voltage signal into a respective cable line by non-contact coupling with twisted pairs in the cable line so that the voltage signal propagates between two or more of the twisted pairs; and

step (ii) includes conveying the same signal to a first pair of electrodes in each of the transmitter coupling units in the selected subset at a substantially the same first time and then, subsequently, conveying the same signal to a second pair of electrodes in each of the transmitter coupling units in the selected subset at a substantially the same second time.

12. The apparatus according to claim 1, wherein the apparatus is additionally for determining the physical state of cable lines in the network and includes a state determining means configured to determine the physical state of cable lines in the network using the transmitter coupling units and the receiver coupling units.

13. The apparatus according to claim 1, wherein the interconnection identification means includes:

at least one signal generating unit configured to generate the test signal; and

conveying means configured to convey the test signal generated by the at least one signal generating unit to the plurality of transmitter coupling units.

14. The apparatus according to claim 13, wherein the conveying means includes at least one splitter unit configured to receive the test signal via a single input signal path from the signal generating unit and to output the test signal via a plurality of output signal paths.

15. The apparatus according to claim 14, wherein each output signal path of the at least one splitter unit includes a

respective switch operable to control whether a test signal is outputted via one or more of the output signal path and a balun.

16. The apparatus according to claim **14**, wherein the conveying means includes at least one further splitter unit configured to receive the test signal via a single input signal path from the output signal path of a splitter unit and to output the test signal via a plurality of output signal paths.

17. The apparatus according to claim **14**, wherein one or more of the splitter units or further splitter units includes a test signal detector for detecting a test signal from the at least one signal generating unit.

18. The apparatus according to claim **14**, wherein the interconnection identification means is configured to identify interconnections between one or more of the signal generating unit, the splitter units and/or the further splitter units by generating test signals using the signal generating unit and detecting the test signals using one or more of the test signal detectors.

19. The apparatus according to claim **13**, wherein the conveying means includes switching means operable to control which of the plurality of transmitter coupling units receives the test signal from the signal generating unit, wherein the switching means includes one or more of:

a respective switch located in each output signal path of at least one splitter unit; and

a respective switch located in each output signal path of at least one further splitter units.

20. The apparatus according to claim **1**, wherein the interconnection identification device includes:

a signal analysing unit for analysing the test signal coupled out from one of the plurality of cable lines by one of the plurality of receiver coupling units; and

conveying means configured to convey the test signal coupled out from one of the plurality of cable lines by one of the plurality of receiver coupling units to the signal analysing unit.

21. The apparatus according to claim **20**, wherein the conveying means includes switching means operable to couple any one of the plurality of receiver coupling units to the signal analysing unit via a signal path which is common to all receiver coupling units.

22. The apparatus according to claim **20**, wherein the switching means includes a respective switch located between each receiver coupling unit and the common signal path.

23. A method of identifying interconnections in a network comprising a plurality of cable lines using an apparatus having:

a plurality of transmitter coupling units, each transmitter coupling unit being configured to couple to a respective one of the plurality of cable lines in the network and to couple a test signal into the respective cable line coupled to the transmitter coupling unit; and

a plurality of receiver coupling units, each receiver coupling unit being configured to couple to the respective one of the plurality of cable lines or another respective one of the plurality of cable lines in the network and, if the test signal is present in the respective cable line, to couple the test signal out from the respective cable line coupled to the receiver coupling unit;

wherein the method includes identifying an interconnection between one of the transmitter coupling units and a selected receiver coupling unit by:

(i) selecting a subset of the transmitter coupling units;

(ii) conveying, at least once, the same test signal to each of the transmitter coupling units in the selected subset at substantially the same time so that, for each of the transmitter coupling units in the selected subset that is coupled to one of the plurality of cable lines, the transmitter coupling unit couples the test signal into the respective cable line coupled thereto;

(iii) determining whether one of the transmitter coupling units of the selected subset of transmitter coupling units is coupled to the same cable line as the selected receiver coupling unit based on whether the selected receiver unit couples out, from the cable line to which it is coupled, the test signal which has propagated directly to the receiver coupling unit from one of the transmitter coupling units in the selected subset; and

(iv) selecting a new subset of the transmitter coupling units based on the determination in step (iii), and performing steps (ii) and (iii) for the newly selected transmitter coupling units; and

(v) if necessary, repeating step (iv) until the interconnection between the transmitter coupling unit and the selected receiver coupling unit is identified.

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